

## STUDY OF THE SORPTION CHARACTERISTICS OF MODIFIED ZEOLITE

*G.Sh. Sultanbaeva, R.A. Kaiynbaeva, R.M.Chernyakova\*, U.Zh. Dzhusipbekov*

*JSC Institute of Chemical Sciences named after A.B. Bekturov, Almaty, Kazakhstan*

*\*Corresponding author e-mail: chernyakova1947@mail.ru*

**Abstract.** *Introduction.* Contaminated industrial wastewater contains carcinogenic metals that negatively affect human health. Research in the field of purification of liquid media polluted with heavy metals focuses on the use of efficient, accessible, inexpensive, and environmentally friendly sorbents and sorption materials based on natural raw materials, in particular zeolite. Natural zeolites from different deposits vary in their mineralogical composition and are characterized by less effective sorption properties compared to synthetic sorbents. To improve the sorption characteristics, an inexpensive modifier guar gum has been selected. *The aim of the work.* Modification of natural zeolite with guar gum by the precipitation method and determination of the optimal conditions under which the highest sorption characteristics are achieved. *Results and discussion.* Study of the effect of guar gum consumption on the properties of modified zeolite showed that with an increase in the amount of modifier, the static exchange capacity (SEC) of the cation exchanger sharply decreases. The optimal stirring time for obtaining the modified sorbent was found to be 10 hours, at which the maximum SEC value of the cation exchanger reaches 1398 mg-eq/g. Investigation of the effect of stirring temperature showed that in the range from 25°C to 75°C, the sorption characteristics of the composite sorbent change insignificantly. An increase in the drying temperature to 100°C leads to an improvement in the sorption characteristics of the sorbent, especially with respect to the sorption of cations. **Conclusion.** The conditions for modifying natural zeolite with a natural polysaccharide (guar gum) by the precipitation method have been studied. Optimal conditions for the modification process have been determined, and a new sorbent has been obtained in which the cation exchange capacity, anion exchange capacity, overall exchange capacity, and total sorption capacity are 15 times, 85.6 times, 9.7 times, and 77 times higher, respectively, compared to natural zeolite.

**Keywords:** natural zeolite, zeolite modification, guar gum, static exchange capacity, total pore volume, overall sorption capacity

<i>Gita Shamilyevna Sultanbayeva</i>	<i>Candidate of technical sciences; E-mail: sultanbaeva@mail.ru</i>
<i>Raushan Alibekovna Kaiynbaeva</i>	<i>Candidate of Technical Sciences; E-mail: raushan_1972@mail.ru</i>
<i>Raissa Michailovna Chernyakova</i>	<i>Doctor of Technical Sciences, Professor; E-mail: chernyakova1947@mail.ru</i>
<i>Umirzak Zhumasilovich Jussipbekov</i>	<i>Academician of the National Academy of Sciences of the Republic of Kazakhstan; E-mail: jussipbekov@mail.ru</i>

**Citation:** Sultanbayeva G.Sh., Kaiynbayeva R.A., Chernyakova R.M., Jussipbekov U.Zh. Study of the sorption characteristics of modified zeolite. *Chem. J. Kaz.*, **2026**, 2(94), 73-80. DOI: <https://doi.org/10.51580/2026-2.2710-1185.15>

## 1. Introduction

The main sources of heavy metals are liquid wastes from the chemical, metallurgical, oil extraction and refining, pharmaceutical, and other industries [1,2].

At present, research in the field of purification of liquid media contaminated with heavy metals is highly relevant, particularly using efficient, accessible, inexpensive, and environmentally friendly sorbents and sorption materials based on natural raw materials. Natural zeolite meets these requirements to a considerable extent, and significant reserves of it are available in Kazakhstan. It should be noted that natural zeolites from different deposits vary in their mineralogical composition, as well as in the content of the main component—clinoptilolite, which determines their sorption characteristics. Natural zeolite is characterized by less effective sorption properties compared, for example, with synthetic ion-exchange resins. However, this drawback is compensated by the good responsiveness of natural zeolite to modification processes.

To improve the sorption characteristics, a suitable low-cost modifier of natural origin—guar gum was selected.

Guar gum is a polymeric compound classified as a polysaccharide, containing functional hydroxyl and  $\text{CH}_2$  groups, with mannose and galactose units. It has sufficient rigidity and enhanced elasticity, is well soluble in water, exhibits good stability, and has a tendency to form structured gels [3–7].

## 2. Experimental part

The experiments were carried out using natural zeolite from the Shankanai deposit (Almaty, Kazakhstan) with the following mass composition: 1.38%  $\text{K}_2\text{O}$ ; 0.95%  $\text{Na}_2\text{O}$ ; 0.16%  $\text{Fe}_2\text{O}_3$ ; 10.81%  $\text{Al}_2\text{O}_3$ ; 2.32%  $\text{CaO}$ ; 0.93%  $\text{MgO}$ ; 65.28%  $\text{SiO}_2$ ; 18.5% loss on ignition. The main sorption properties of the zeolite are as follows: static exchange capacity for cations – 0.997 mg-eq/g, static exchange capacity for anions – 0.4985 mg-eq/g, total pore volume – 0.07  $\text{cm}^3/\text{g}$ .

The modification of natural zeolite was carried out as follows: natural zeolite with a particle size of 1–1.5 mm and guar gum were added to distilled water. The resulting mixture was stirred, after which the solid phase was separated from the liquid phase by filtration, and the obtained solid sorbent was dried.

The sorption characteristics of the sorbent are significantly influenced by the ratio of the initial components, mixing time, mixing temperature, drying temperature and time, and zeolite consumption. The influence of these factors on the modification process of natural zeolite with guar gum was studied using a one-factor-at-a-time method.

Methods for determining the parameters of the porous structure of adsorbents were applied. The main sorption characteristics were determined according to standard methods [8, 9].

### 3. Results and discussion

The results of studying the effect of guar gum consumption on the properties of modified zeolite, presented in Table 1, showed that with an increase in the amount of modifier (guar gum), the static exchange capacity (SEC) of the cation exchanger sharply decreases.

**Table 1** – Effect of guar gum consumption on the properties of modified zeolite

Experiment number	Consumption of GKam, g	SEC, mg-eq/g		TSC, mg-eq/g	TPV, g/cm <sup>3</sup>
		cation exchanger	anion exchanger		
1	0.1	25.54	10.9	60.57	0.3022
2	0.2	5.73	17.83	65.09	0.0384
3	0.3	6.87	26.52	69.43	0.3208
4	0.5	5.92	26.57	70.82	0.3594
5	0.7	4.89	30.21	66.85	0.7668

Thus, at a guar gum consumption of 0.2 g (Experiment 2), the static exchange capacity (SEC) of the cation exchanger decreases by 4.5 times compared to Experiment 1. The static exchange capacity of the anion exchanger increases by 2.4–2.7 times when the amount of guar gum is increased from 0.1 to 0.7 g. Increasing the amount of guar gum from 0.1 to 0.7 g leads to a 2.5-fold increase in its overall sorption capacity compared to the standard for guar gum. The change in overall sorption capacity relative to the standard reaches an extremum, with a maximum at 0.5 g of guar gum (Experiment 4).

The total pore volume (TPV) changes only slightly from Experiment 1 to 4, increasing 2.5 times at a guar gum consumption of 0.7 g. Since the sorbent is intended for the sorption of heavy metal cations, a guar gum concentration was selected at which the SEC of the cation exchanger is maximized, i.e., 0.1 g.

The study of the effect of mixing time on the properties of the sorbent (Table 2) showed that increasing the mixing time affects the static exchange capacity (SEC) of the cation and anion exchangers, the overall sorption capacity (OSC), and the TPV.

Specifically, when the mixing time is increased from 2 to 10 hours (Experiments 1–3), the SEC of the cation exchanger significantly increases—from 0.299 to 1.398 mg-eq/g, i.e., by 4.7 times. This indicates a more complete activation of the sorbent due to the extended contact time of the components. However, further increasing the mixing time to 15 hours (Experiment 4) leads to a decrease in SEC to 1.098 mg-eq/g, which may be associated with the onset of sorbent structure degradation or reduced accessibility of active sites.

The SEC of the anion exchanger changes only slightly, ranging from 14.569 to 15.293 mg-eq/g. The total sorption capacity increases from 68.217 to 73.939 mg-eq/g when the mixing time is increased up to 10 hours, after which it decreases to 66.575 mg-eq/g at 15 hours, demonstrating an extremal behavior with a maximum at 10 hours. The TPV varies slightly, from 0.8612 to 0.9387

cm<sup>3</sup>/g. The highest value is observed at the shortest mixing time (Experiment 1), after which the volume gradually decreases. Since the sorbent is primarily used for the sorption of heavy metal cations, the optimal mixing time is 10 hours (Experiment 3), at which the maximum SEC of the cation exchanger–1.398 mg-eq/gis achieved.

**Table 2** – Effect of mixture mixing time on the properties of modified zeolite

Experiment number	$\tau$ mixing, h	SEC,mg-eq/g		TSC, mg-eq/g	TPV, g/cm <sup>3</sup>
		cation exchanger	cation exchanger		
1	2	0.299	15.293	68.217	0.9387
2	5	0.469	15.054	70.389	0.9219
3	10	1.398	14.569	73.939	0.8612
4	15	1.098	14.656	66.575	0.9285

The study of the effect of mixing temperature (Table 3) on the properties of the sorbent showed that changes in mixing temperature in the range from 25°C to 75°C have little effect on the sorption characteristics of the composite sorbent. The SEC of the cation exchanger ranges from 11.88 to 13.94 mg-eq/g, and the SEC of the anion exchanger from 47.43 to 50.04 mg-eq/g. The total sorption capacity varies from 51.05 to 56.52 mg-eq/g. The total pore volume also remains stable, ranging from 0.929 to 0.9764 cm<sup>3</sup>/g. Considering technological simplicity and economic feasibility, the mixing was carried out at room temperature (25°C) in subsequent experiments and production.

**Table 3** – Effect of mixture mixing temperature on the properties of modified zeolite

Experiment number	T of mixing, °C	SEC,mg-eq/g		TSC, mg-eq/g	TPV, g/cm <sup>3</sup>
		cation exchanger	cation exchanger		
1	25	13.41	47.43	53.22	0.9764
2	40	12.53	50.04	51.048	0.973
3	55	13.94	47.25	56.52	0.929
4	75	11.88	48.467	54.65	0.937

The results of studying the effect of sorbent drying temperature on the properties of modified zeolite are presented in Table 4.

The data show that the drying temperature significantly affects the sorption properties of the composite sorbent. Increasing the drying temperature from 25°C to 100°C leads to an increase in the static exchange capacity of the cation exchanger from 15.87 to 18.87 mg-eq/g. The highest value is observed at 100°C (Experiment 4), indicating a positive effect of elevated drying temperature on the activation and structural stability of the sorbent. This may be associated with the removal of excess moisture and stronger fixation of guar gum within the zeolite structure.

**Table 4** – Effect of sorbent drying temperature on the properties of modified zeolite

Experiment number	T <sub>Sorbent drying</sub> , °C	SEC, mg-eq/g		TSC, mg-eq/g	TPV, g/cm <sup>3</sup>
		cation exchanger	cation exchanger		
1	25	15.87	46.92	50.07	1.4313
2	50	15.65	48.49	49.75	1.4091
3	80	16.81	48.52	42.98	1.5394
4	100	18.87	49.51	52.19	1.5804

The SEC of the anion exchanger changes only slightly, ranging from 46.92 to 49.51 mg-eq/g, showing no pronounced dependence on the drying temperature. The total sorption capacity also increases from 50.07 to 52.19 mg-eq/g, which corresponds with the growth in the SEC of the cation exchanger. The total pore volume increases with higher temperature, reaching a maximum of 1.5804 cm<sup>3</sup>/g at 100°C. This indicates the formation of a more porous material structure during high-temperature drying.

Thus, increasing the drying temperature to 100°C improves the sorption characteristics of the sorbent, particularly with respect to cation sorption. Therefore, a drying temperature of 100°C can be recommended for further studies and potential industrial applications.

Next, the effect of sorbent drying time on the sorption characteristics of the synthesized sorbent was studied. The results (Table 5) show that varying the drying time in the range of 0.5 to 2.5 hours has little effect on the SEC of the cation exchanger.

**Table 5** – Effect of sorbent drying time on the properties of modified zeolite

Experiment number	τ <sub>sorbent drying</sub> , h	SEC, mg-eq/g		TSC, mg-eq/g	TPV, g/cm <sup>3</sup>
		cation exchanger	cation exchanger		
1	0.5	5.940	28.71	17.74	1.553
2	1	5.923	34.62	23.31	1.543
3	1.5	5.917	30.78	18.52	1.721
4	2.5	5.952	32.64	24.05	1.694

The values of the SEC for the cation exchanger vary within a very narrow range, from 5.917 to 5.952 mg-eq/g, indicating the stability of cation-exchange properties with changes in drying time.

The SEC of the anion exchanger shows more pronounced fluctuations, ranging from 28.71 to 34.62 mg-eq/g, with the maximum observed after 1 hour of drying (Experiment 2). However, after 1.5–2.5 hours, a slight decrease is observed, which may be related to partial loss of active surface area or changes in the structure of the polymer component. The TSC varies from 17.74 to 24.05 mg-eq/g, reaching a maximum after 2.5 hours (Experiment 4), indicating a slight increase in sorbent efficiency with longer drying. The TPV ranges from 1.543 to

1.721 cm<sup>3</sup>/g and does not show a consistent dependence on drying time, with the highest value observed at 1.5 hours (Experiment 3), followed by a slight decrease.

Thus, drying time in the range of 0.5–2.5 hours does not significantly affect the cation-exchange properties, although a slight improvement in TSC is observed at longer drying times up to 2.5 hours. Nevertheless, for practical applications, considering energy consumption and the minimal difference in results, the minimum drying time of 0.5 hours is recommended.

The optimal conditions for the modification process have been determined as follows: volume of distilled water for preparing the guar gum solution – 200 mL; guar gum consumption – 0.1 g; natural zeolite consumption – 10 g; mixing time of zeolite with guar gum – 10 hours; mixing temperature – 25°C; drying temperature of the sorbent – 50°C; drying time – 2.5 hours.

As shown in Table 6, compared to natural zeolite, the modified zeolite exhibits some changes in total pore volume, iodine sorption capacity (E), and cation exchange capacity (SEC).

**Table 6** – Main properties of modified and natural zeolites

TPV, g/cm <sup>3</sup>	TSC, g/cm <sup>3</sup>	SEC <sub>cat exc</sub> , mg-eq/g	SEC <sub>anexc</sub> , mg-eq/g
Modified zeolite			
1.814	35.44	14.896	42.658
Natural zeolite			
0.0235	3.67	0.997	0.4985

The TPV and the SEC of the anion exchanger increase by 1.14 and 1.12 times, respectively. The improvement in the sorption properties of the modified zeolite is expected to enhance its sorption capacity for heavy metal cations as well.

#### 4. Conclusion

The conditions for modifying natural zeolite with a natural polysaccharide (guar gum) using the precipitation method have been studied. The optimal synthesis conditions for the new sorbent, corresponding to high sorption characteristics, have been determined. A new sorbent has been obtained, in which the cation exchange capacity, anion exchange capacity, overall sorption capacity (TSC), and total pore volume (TPV) are 15, 85.6, 9.7, and 77 times higher, respectively, compared to natural zeolite.

**Acknowledgments:** This work was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR27101179, «Fundamentals of obtaining innovative, environmentally friendly, multifunctional chemical products and materials»).

**Conflict of Interest:** All authors declare that they have no conflict of interest.

## МОДИФИКАЦИЯЛАНҒАН ЦЕОЛИТТИҢ СОРБЦИЯЛЫҚ СИПАТТАМАЛАРЫН ЗЕРТТЕУ

*Сұлтанбаева Г.Ш., Қайыңбаева Р.А., Чернякова Р.М., Жүсіпбеков Ө.Ж.*

*Ә.Б. Бектұров атындағы Химия ғылымдары институты, Алматы, Қазақстан*

**Түйіндемe.** *Кіріспе.* Ластанған өнеркәсіптік ағынды суларда адам денсаулығына кері әсерететін канцерогенді металдар бар. Тиімді, қолжетімді, арзан және экологиялық таза сорбенттер мен табиғи шикізатқа, атап айтқанда цеолит кенегізделген сорбциялық материалдарды пайдалана отырып, ауыр металдармен ластанған сұйық ортаны тазарту процестері саласындағы зерттеулер өзекті болып табылады. Әр түрлі кен орындарынан алынған табиғи цеолиттер минералогиялық құрамы бойынша ерекшеленеді және синтетикалық сорбенттер мен салыстырғанда тиімділігі төмен сорбциялық қасиеттерімен сипатталады. Сорбциялық сипаттамаларды жақсарту үшін арзан модификатор – гуар шайыры таңдалды. *Мақсаты.* Табиғи цеолитті гуар шайырымен тұндыру арқылы модификациялау және ең жоғары сорбциялық сипаттамаларға жету үшін оңтайлы жағдайларды анықтау. *Нәтижелер және талқылау* Гуар шайыры мөлшерінің модификацияланған цеолиттің қасиеттеріне әсерін зерттеу модификатор мөлшерінің артуымен катион алмастырғыштың статикалық алмасу сыйымдылығы (САС) күрт төмендейтінін көрсетті. Модификацияланған сорбентті алудың оңтайлы араластыру уақыты (10 сағат) анықталды, катион алмасу шайырының КАСмаксималды мәні 1398 мг-экв/г-ға жетті. Араластыру температурасының әсерін зерттеу композиттік сорбенттің сорбциялық қасиеттерінің 25°C-тан 75°C-қа дейінгі диапазонда елеусіз өзгеретінін көрсетті. Кептіру температурасын 100°C-қа дейін көтеру сорбенттің сорбциялық қасиеттерін, әсіресе сорбцияға қатысты катиондық қасиетін жақсартады. *Қорытынды.* Табиғи цеолитті табиғи полисахаридпен (гуаршайыры) тұндыру арқылы модификациялау шарттары зерттелді. Сорбентті модификациялау процесінің оңтайлы шарттары анықталды және катиондық шайырдың сорбциялық сыйымдылығы, аниондық шайырдың сорбциялық сыйымдылығы және ЖКК мәндері табиғи цеолитпен салыстырғанда сәйкесінше 15 есе, 85,6 есе, 9,7 есе және 77 есе жоғары жаңа сорбент алынды.

**Түйін сөздер:** табиғи цеолит, цеолит модификациясы, гуаршайыры, статикалық алмасу сыйымдылығы, жалпы кеуек көлемі, жалпы сорбциялық сыйымдылық

<i>Сұлтанбаева Гита Шамилқызы</i>	<i>Техника ғылымдары кандидаты</i>
<i>Қайыңбаева Раушан Әлібекқызы</i>	<i>Техника ғылымдары кандидаты</i>
<i>Чернякова Раиса Михайловна</i>	<i>Техника ғылымдары докторы</i>
<i>Жүсіпбеков Өмірзақ Жұмасылұлы</i>	<i>Техника ғылымдары докторы</i>

## ИЗУЧЕНИЕ СОРБЦИОННЫХ ХАРАКТЕРИСТИК МОДИФИЦИРОВАННОГО ЦЕОЛИТА

*Сұлтанбаева Г.Ш., Қайыңбаева Р.А., Чернякова Р.М.\*, Джусіпбеков У.Ж.*

*АО Институт химических наук им. А.Б. Бектұрова, Алматы, Казахстан*

**Резюме.** *Введение.* Загрязненные производственные стоки содержат канцерогенные металлы, негативно влияющие на здоровье человека. Исследования в области процессов очистки жидких сред, загрязненных тяжелыми металлами, с использованием эффективных, доступных, недорогих и экологически чистых сорбентов и сорбционных материалов на основе природного сырья, в частности цеолитов являются актуальными. Природные цеолиты различных месторождений различаются по своему минералогическому составу, характеризуются менее эффективными сорбционными свойствами по сравнению с синтетическими сорбентами. Для улучшения сорбционных характеристик подобран недорогой модификатор - гуаровая камедь. *Цель работы.* Модификация природного цеолита гуаровой камедью методом осаждения и определение оптимальных условий, при которых достигается максимально высокие сорбционные

характеристики. *Результаты и обсуждение.* Изучение влияния расхода гуаровой камеди на свойства модифицированного цеолита показало, что с увеличением расхода модификатора статическая обменная емкость (СОЕ) катионита резко снижается. Найдено оптимальное время перемешивания при получении модифицированного сорбента (10 часов), при котором достигается максимальное значение СОЕ катионита - 1398 мг-экв/г. Изучение влияния температуры перемешивания показало, что в диапазоне от 25°C до 75°C сорбционные характеристики композитного сорбента изменяются незначительно. А повышение температуры сушки до 100 °C приводит к улучшению сорбционных характеристик сорбента, особенно в отношении сорбции катионов. *Заключение.* Изучены условия модификации природного цеолита природным полисахаридом (гуаровой камедью) методом осаждения. Определены оптимальные условия проведения процесса модификации сорбента и получен новый сорбент, в котором сорбционная емкость по катиониту, сорбционная емкость по аниониту, СОЕ и СОП в 15 раз, в 85.6 раз, в 9.7 раз и в 77 раз больше по сравнению с природным цеолитом.

**Ключевые слова:** природный цеолит, модификация цеолита, гуаровая камедь, статическая обменная емкость, суммарный объем пор, общая сорбционная емкость

<i>Гита Шамильевна Султанбаева</i>	<i>Кандидат технических наук</i>
<i>Раушан Алибековна Кайынбаева</i>	<i>Кандидат технических наук</i>
<i>Раиса Михайловна Чернякова</i>	<i>Доктор технических наук, профессор</i>
<i>Умирзак Жумасилович Джусупбеков</i>	<i>Академик НАН РК, профессор, доктор технических наук</i>

## References

1. Pal S., Patra A.S., Ghorai S., Sarkar A.M., Mahato V., Sarkar S., Singh R.P. Efficient and rapid adsorption characteristics of templating modified guar gum and silica nanocomposite toward removal of toxic reactive blue and Congo red dyes, *Bioresour. Technol.* **2015**. 291–299. <https://doi.org/10.1016/j.biortech.2015.04.099>
2. Medvedev I.F., Derevyagin S.S. *Heavy metals in ecosystems. Monograph.* Saratov: ООО «Rakurs», **2017**. 178 p. ISBN: 978-5-9758-1665-8. <https://w.eruditor.one/file/2419157/>
3. Osovskaya I.I., Antonova V. Effect of Acid and Enzymatic Hydrolysis of Cellulose on its Physicochemical Properties for Improved Moisture-Absorption DOI: 10.1007/s10692-025-10603-9
4. Influence of capillary-porous structure of cellulose on physicochemical properties of fibrous material. Polomarchuk D.A., Osovskaya I.I., Sevastyanova J.V., Bogolitsyn K. G., Parshina A., Bogdanovich N.I. *Chemistry of plant raw material.* **2025**, no. 1, pp. 351–362. DOI: 10.14258/jcprm.20250114679
5. Electronic resource: [www.frontiersin.org/journals/chemistry/articles/10.3389/fchem.2024.1410876/full](http://www.frontiersin.org/journals/chemistry/articles/10.3389/fchem.2024.1410876/full) (accessed 21.04.2025).
6. Bobylev A.E. *Synthesis, structure, and functional properties of composite sorbents “Cationite KU-3x9-MeS [Me – Cu(II), Zn, Pb]”* / PhD dissertation, Physical Chemistry, Ural Federal University named after the first President of Russia B.N. Yeltsin, Yekaterinburg, **2016**. 160 p. <https://search.rsl.ru/ru/record/01008692224>
7. Shkuratov A.L. *Preparation of sorbents and membranes based on natural silicates for purification of solutions from pollutants of various nature* / PhD dissertation, Ecology (Chemistry), Far Eastern Federal University, Vladivostok, **2018**. 156 p. <https://search.rsl.ru/ru/record/01009702096>
8. Koganovsky A.M., Levchenko T.M., Kirichenko V.A. *Adsorption of dissolved substances.* Kyiv, **1977**. 250 p. <https://search.rsl.ru/ru/record/01007677156>
9. GOST 4453-74. *Powdered activated carbon for clarification.* Moscow: Standards Publishing, **1993**. 6 p.