[Reviewer 1]

- **Comments and Suggestions for Authors**

The removal Sr2+ in aqueous solution With Na-A zeolites, which were synthesized from kaolin and with different ratios 0.6 (ZH06) and 0.9 (ZH09). The absorption was achieved in120 min. The experimental absorption was estimated: pseudo-2nd-order kinetic and Langmuir isotherm models.

The introduction is complete and very interesting. The references are complete. The paper is well written and well organized but is necessary que the authors written with major detail which is the novelty of this manuscript. What is the new part and that was described previously in the literature, in particular compared with reference [11].

: Thank you for your time and comments. Modified parts in the manuscript are marked in red.

1) The samples KH06 and KH09 has been previously described in the literature. Fig. 1 is of the authors, or previously presented in the literature? Ref. [11]

: We used non-identical SEM images of samples from previous papers (before revision [11] and after revision [15]).

2) In Fig. 2, the three compounds present the same XRD, the only difference is the intensity of peaks. Comment with major detail.

: We added the following comment to lines 81-87:

"To determine that the crystal structures of ZK06 and ZK09 were formed through the synthesis process, their X-ray diffraction (XRD) patterns were compared with the commercial Na-A zeolite as the standard. Figure 2 shows that as the NaOH/kaolin mass ratio increases, its XRD pattern and peak intensity become closer to that of the commercial Na-A zeolite (H74Al11.8Na13.1O85Si12.2). When the XRD pattern of ZK06 has a low NaOH/kaolin mass ratio, low-intensity peaks remain, suggesting the presence of amorphous components that have not yet been crystallized."

3) Revise Fig. 4, add greater number of points.

: To clearly show the line fitting of the adsorption results, the results above 3.5 mmol/L were cropped. Please understand.

4) The Part 4, Discussion is repetitive. Add the part important in Conclusions.

: We revised Sections 4 and 5, excluding duplicates. Please check lines 191-217.

- **Comments on the Quality of English Language**

Moderate English is necessary.

: To ensure a smooth flow of text, the English text was re-edited by 'Editage'. A certificate of English proofreading has been submitted as an attachment.

materials

MDPI

Article

Removal of strontium ions from aqueous solution using Na-A zeolites synthesized from kaolin

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Abstract: Sr^{2+} ions in an aqueous solution were removed using Na-A zeolites synthesized from kaolin, a natural mineral. Na-A zeolites with high crystallinity were synthesized using NaOH/kaolin mass ratios of 0.6 (ZK06) and 0.9 (ZK09). The adsorption reached equilibrium within 120 min. The adsorption data obtained from experiments for Sr^{2+} using ZK06 and ZK09 were appropriately analyzed with pseudo-second-order kinetic and Langmuir isotherm models. Comparing the maximum adsorption capacities (q_m) of ZK06 and ZK09 for Sr^{2+}, the highest values were obtained at 1.90 and 2.42 mmol/g, respectively. Consequently, the Na-A zeolites synthesized from kaolin can be evaluated as adsorbents with high adsorption capacities for the removal of Sr^{2+}, proportional to the degree of their crystallinity.

Keywords: Adsorption; Na-A zeolite; Crystallinity; Radioactive waste; Strontium

1. Introduction

Nuclear power plants (NPPs) are actively operated worldwide to generate electricity, and their radioactive waste is considered a hazardous contaminant. The accumulation potential of radioactive elements in animals and plants causes serious human health and environmental problems owing to their relatively long half-lives [1, 2]. Radioactive waste is generated in a wide range of industries, such as nuclear power plants, mining, and medicine, and large amounts of strontium are present in such waste [3]. Strontium can be deposited in the human body, which can cause bone cancer and leukemia with a highly radioactive poison [4].

Zeolites are aluminosilicate structures consisting of tetrahedral SiO_4 and AlO_4 linked by shared oxygen bridges that form cages that can capture diverse hydrated ions depending on their size [5, 6]. The advantages of using zeolites in the safe treatment of radioactive waste are their high selectivity and excellent radiation resistance [7]. Na-A zeolite is one of the low-silica zeolites with an Si/Al content ratio of 1 that has a hexahedron structure [8]. While high-alumina zeolites are unsuitable as catalysts due to their lack of acidity, Na-A zeolites are appropriate for adsorption reactions due to the large density of cation-capturing sites on the framework. Owing to their characteristically high cation-exchange capacity (CEC), Na-A zeolites are widely used for removing toxic metal ions and radionuclides from aqueous solutions in wastewater treatment. In particular, since the pore apertures of Na-A zeolites are in the range of 0.23 nm to 0.42 nm, they can be considered to

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have a framework structure suitable for capturing Sr^{2+}, which has a hydration radius of approximately 0.41 nm [9].

Among the various synthesis methods for producing Na-A zeolites, hydrothermal and fusion/hydrothermal methods are widely used in the synthesis of inexpensive raw materials such as coal fly ash, blast-furnace slag, waste sludge, lithium slag, and natural minerals [10]. Kaolin is a low-cost raw material and is abundant across the world. When kaolin is used as a synthetic raw material, Na-A zeolites can be obtained by dissolving metakaolin in a sodium hydroxide (NaOH) solution without adding any other silica or alumina sources [11].

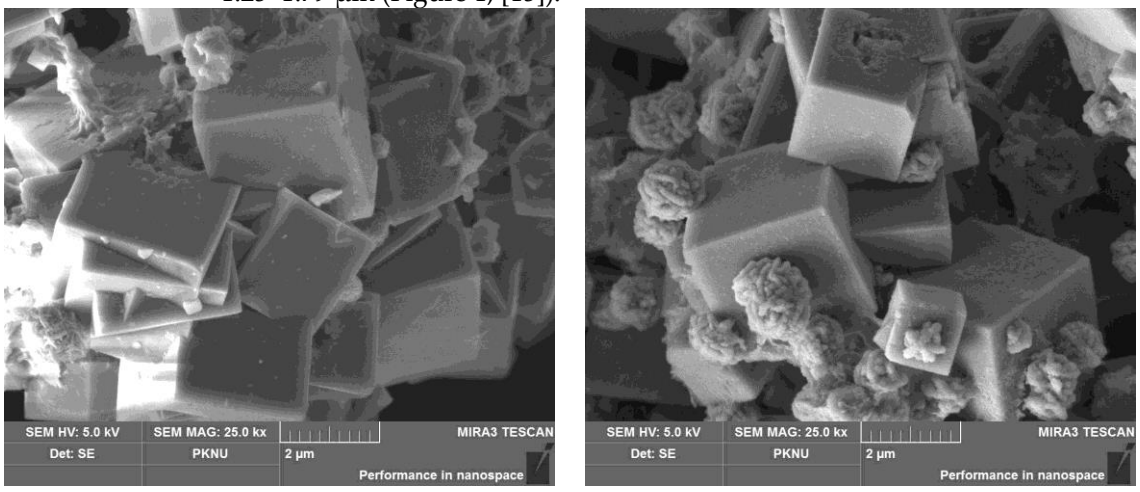
Researchers have developed approaches to evaluate methods for removing radioactive elements using various zeolites as adsorbents. Smiciklas et al. [12] fitted their experimental results to the Langmuir isotherm model and demonstrated that the adsorption capacities of natural zeolites for Cs^{2+}, Co^{2+}, and Sr^{2+} were 0.03, 0.56, and 0.11 mmol/g, respectively. El-Kamash used the pseudo-second-order kinetic and Langmuir models and showed that the removal efficiency of synthetic Na-A zeolite for Sr^{2+} was 0.79 mg/g [13]. Lee et al. performed the Sr^{2+} removal in an aqueous solution using synthesized Na-A zeolite from coal fly ash (CFA), and the process presented an adsorption capacity of 1.78 mmol/g [14]. Despite several studies, there is a lack of research on the Sr^{2+} adsorption characteristics of zeolites based on their crystallinity.

In a previous study, it was confirmed that kaolin, an inexpensive and natural clay mineral, was successfully converted into Na-A zeolites using a fusion/hydrothermal method [15]. In this study, we focused on the removal of Sr^{2+} from aqueous solutions and evaluated the adsorption capacities of synthesized Na-A zeolites as adsorbents. The experimental data were analyzed by model fitting with adsorption kinetic and isotherm models to evaluate the characteristics of adsorption for Sr^{2+} on the samples. For adsorption kinetics, the pseudo-first- and second-order models were applied, while the Langmuir and Freundlich models were employed for the adsorption isotherm.

2. Materials and Methods

2.1. Materials

Na-A zeolites were synthesized from natural kaolin using the fusion/hydrothermal method with different NaOH/kaolin mass ratios of 0.6 and 0.9. These samples were named ZK06 and ZK09, respectively. They had a cubic morphology with mean particle sizes of 1.25–1.79 μm (Figure 1, [15]).



(**a**) (**b**)

Figure 1. FE-SEM images of samples: (**a**) ZK06 with median particle size of 1.79 μm and (**b**) ZK09 with median particle size of 1.25 μm.

To determine that the crystal structures of ZK06 and ZK09 were formed through the synthesis process, their X-ray diffraction (XRD) patterns were compared with the commercial Na-A zeolite as the standard. Figure 2 shows that as the NaOH/kaolin mass ratio increases, its XRD pattern and peak intensity become closer to that of the commercial Na-A zeolite ($H_{74}Al_{11.8}Na_{13.1}O_{85}Si_{12.2}$). When the XRD pattern of ZK06 has a low NaOH/kaolin mass ratio, low-intensity peaks remain, suggesting the presence of amorphous components that have not yet been crystallized.

The crystallinity for evaluating the synthesis efficiency of the sample was approximated by taking the ratio of the sum of the integrated peak areas of the sample to the sum of the integrated peak areas of commercial Na-A zeolite that appear intrinsically at 2θ values of 7.20°, 10.18°, 12.46°, 16.10°, 21.66°, 23.98°, 26.10°, 27.10°, 29.92°, 30.82°, 32.52°, and 34.16° [16, 17]. The degree of crystallinity was calculated using Equation (1):

$$\%Crystallinity = \left(\frac{\sum Integrated\ peak\ areas\ of\ sample}{\sum Integrated\ peak\ areas\ of\ commercial\ Na\text{-}A\ zeolite}\right) \times 100 \quad (1)$$

Commercial Na-A zeolite was purchased from FUJIFILM Wako Pure Chemical Corporation (Osaka, Japan) and used as a standard in crystallinity calculations. Based on the XRD results, when the NaOH/kaolin mass ratio mounted from 0.6 to 0.9, the crystallinity of the samples increased from approximately 64% (ZK06) to 84% (ZK09).

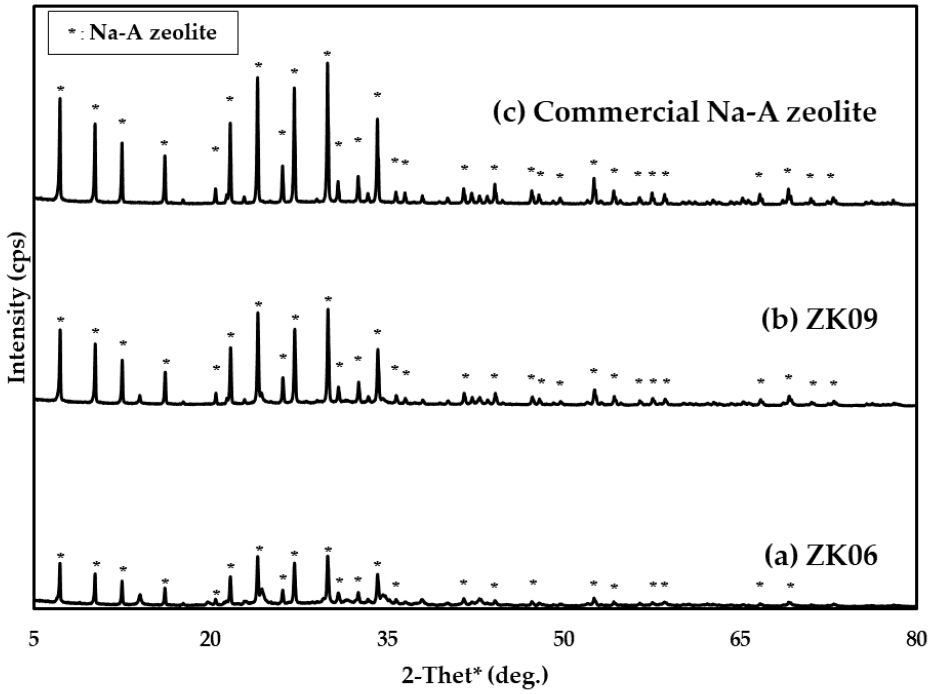


Figure 2. XRD patterns of hydrothermally synthesized Na-A zeolites with NaOH/kaolin mass ratios of (**a**) 0.6 (ZK06) and (**b**) 0.9 (ZK09). For calculating crystallinity, (c) commercial Na-A zeolite was used as a standard (reused with permission and modified after [15]).

2.2. Adsorption Performance and Characterization

For batch adsorption experiments, stock solutions were prepared using strontium nitrate ($Sr(NO_3)_2$, EP grade, Samchun, Korea), and deionized water was used in all experiments. 0.05 g of ZK06 and ZK09 were added to conical centrifuge tubes (Falcon, 352070) containing 50 mL of the Sr2+ stock solution at 25 °C. At the same time, the pH was adjusted

to 5.0 by the addition of 0.1 M HCl or NaOH. The prepared samples were stirred at 25 °C and 180 rpm in an orbital shaker (VS-8480SF, Vision Scientific Co., Ltd., Daejeon, Korea). After stirring and reaction, the samples were centrifuged at 3,000 rpm for 3 min using a centrifuge (VS-5500i, Vision Scientific Co., Ltd., Daejeon, Korea). The supernatants were filtered, and Sr^{2+} ion concentrations were determined using ICP-OES (Optima 8300, Perkin Elmer, Massachusetts, USA).

2.2.1. Adsorption kinetic models

To determine the kinetic characteristics of Sr^{2+} on the samples in the aqueous solution and to fit the experimental data, the pseudo-first- and pseudo-second-order kinetic models were employed. The pseudo-first-order model is expressed as follows [18]:

$$\frac{dq}{dt} = k_1(q_e - q), \quad (2)$$

where q is the adsorption capacity (mmol/g) at time, q_e is the adsorption capacity (mmol/g) after equilibrium, and k_1 is the rate constant of adsorption (1/min). With the boundary conditions at $t = 0$ *to* $t = t$ and $q = 0$ *to* $q = q$, Equation (2) can be integrated and yields

$$ln(q_e - q_t) = ln(q_e) - k_1 t. \quad (3)$$

The pseudo-second-order model for the adsorption can be expressed as follows [13]:

$$\frac{dq}{dt} = k_2(q_e - q)^2. \quad (4)$$

With the boundary conditions at $t = 0$ *to* $t = t$ and $q = 0$ *to* $q = q$, Equation (4) can be integrated and yields

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t, \quad (5)$$

where k_2 is the adsorption rate constant (g/mg·min) determined from Equation (5), and a linear equation is obtained.

2.2.2. Adsorption isotherm models

To determine the adsorption equilibrium data for Sr^{2+} on the samples in aqueous solutions and to fit the experimental data, the Langmuir and Freundlich isotherm models were employed. The Langmuir model can be expressed as follows [19]:

$$q_e = \frac{k_L q_m C_e}{1 + k_L C_e}, \quad (6)$$

where k_L is a Langmuir constant (L/mg) and q_m is the maximum adsorption capacity (mmol/g).

The Freundlich model can be expressed as follows [20]:

$$q_e = k_F C_e^{\frac{1}{n}}, \quad (7)$$

where k_F is the Freundlich constant (mmol/g) $(L/mmol)^{1/n}$ and 1/n is a Freundlich constant related to the adsorption strength.

3. Results

3.1. Adsorption Kinetics of Sr^{2+}

The experimental adsorption data for Sr^{2+} using ZK06 and ZK09 analyzed by model fitting with the pseudo-first- and second-order kinetic models are displayed in Figure 3.

The plots show that the adsorption capacities of Sr^{2+} onto the samples increased rapidly within the initial 15 min, and the adsorption reached equilibrium after 120 min. The adsorption kinetic parameters for Sr^{2+} onto the samples obtained from the experimental data obtained using Equations (2) and (4) are listed in Table 1.

From the pseudo-first order kinetic plots, $\ln(q_e-q)$ against t yields linear lines with slopes of k_1 and intercepts of $\ln(q_e)$, whereas from the second-order kinetic plots, t/q_t against t produces linear lines with slopes of $1/q_e$ and intercepts of $1/k_2q_e^2$. Furthermore, q_e, k_1, and k_2 values are obtained from the slopes and intercepts of these kinetic models. Compared to the equilibrium adsorption capacity ($q_{e,exp}$) obtained directly from experiments, as summarized in Table 1, the q_e values estimated from the kinetic models were similar to the $q_{e,exp}$ values obtained from the pseudo-second-order model but were significantly different from those obtained from the pseudo-first-order model. In addition, the coefficient of determination, r^2, was calculated as 0.9849 and 0.9965 with the pseudo-second-order model, and the results were relatively higher than those of the pseudo-first-order model. Therefore, the pseudo-second-order model can be considered more suitable in terms of characterizing the adsorption kinetics of Sr^{2+}.

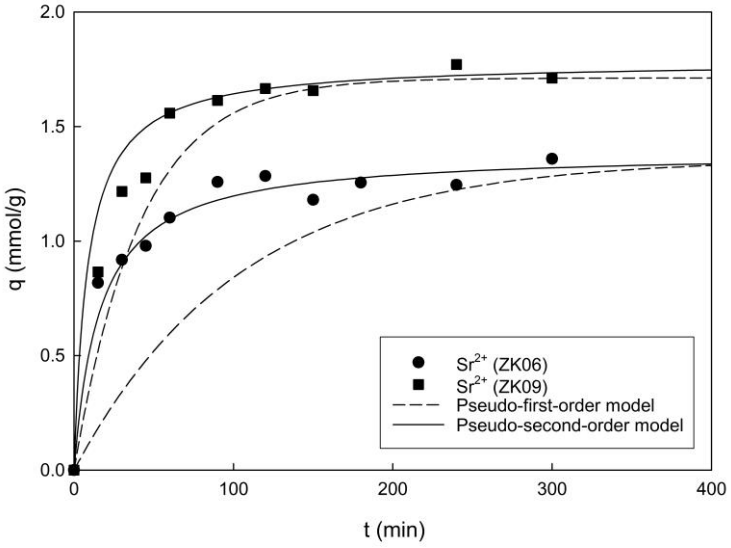


Figure 3. Experimental adsorption results fitted according to the kinetic models for Sr^{2+} using ZK06 and ZK09 with NaOH/kaolin mass ratios of 0.6 and 0.9 (dosage of adsorbents = 1 g/L).

Table 1. Calculated kinetic parameters for the adsorption of Sr^{2+} onto ZK06 and ZK09 with NaOH/kaolin mass ratios of 0.6 and 0.9.

Sample	C_0 (mmol/L)	$q_{e,exp}$ (mmol/g)	Pseudo-first-order model			Pseudo-second-order model		
			q_e (mmol/g)	k_1 (1/h)	r^2	q_e (mmol/g)	k_2 (mmol/g·h)	r^2
ZK06	2.56	1.36	0.5587	0.0334	0.6319	1.3918	0.0442	0.9849
ZK09	2.56	1.71	1.1294	0.0089	0.9157	1.7845	0.0648	0.9965

3.2. Adsorption Isotherms of Sr^{2+}

The results of the adsorption isotherm experiment and the corresponding model fittings for Sr^{2+} are shown in Figure 4. The experimental adsorption isotherm data were analyzed using the Langmuir and Freundlich models, and the calculated parameters are listed in Table 2. Non-linear and linear isotherm models were compared based on parameters with coefficient of determination (r^2). The r^2 values of the Langmuir model were computed to be 0.9980 and 0.9963, which were comparatively higher than those of the Freundlich model. Accordingly, the Langmuir model is evaluated to be more suitable for the characterization of isotherms for Sr^{2+}.

The values of the maximum adsorption capacities, q_m, of ZK06 and ZK09 for Sr^{2+} drawn from the Langmuir model were 1.90 and 2.42 mmol/g, respectively. Moreover, when natural zeolite was used, the q_m for Sr^{2+} obtained using the Langmuir model was 0.11 mmol/g [14]. Using the fusion method from CFA, Murukutti and Jena [21] calculated the q_m of a synthesized Na-A zeolite for Sr^{2+} to be 1.09 mmol/g. The q_m values of ZK06 and ZK09 for $Sr^{2+,}$ were approximately 73.6% and 93.4%, respectively, compared to 2.59 mmol/g of commercial Na-A zeolite [2]. Therefore, the Na-A zeolites synthesized from kaolin used in this study can be evaluated as efficient adsorbents for the removal of Sr^{2+}.

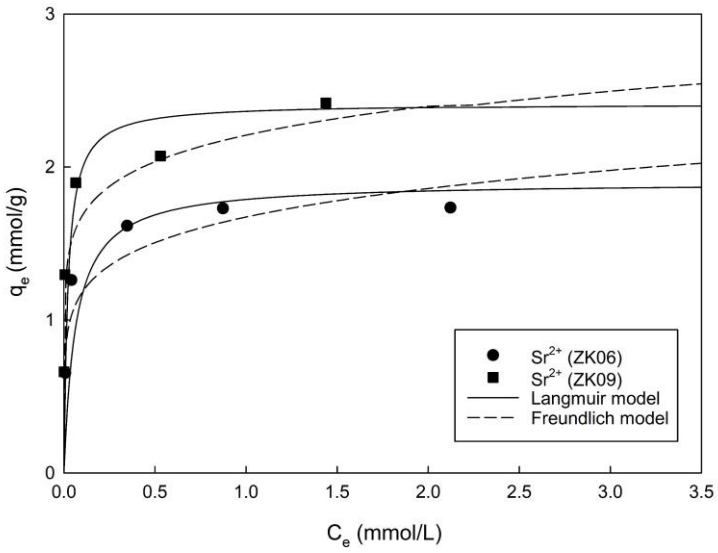


Figure 4. Experimental adsorption results fitted according to the isotherm models for Sr^{2+} using ZK06 and ZK09 with NaOH/kaolin mass ratios of 0.6 and 0.9 (dosage of adsorbents = 1 g/L).

Table 2. Calculated isotherm parameters for the adsorption of Sr^{2+} onto ZK06 and ZK09 with each NaOH/kaolin mass ratio of 0.6 and 0.9.

Sample	Langmuir model			Freundlich model		
	q_m (mmol/g)	k_L (L/mmol)	r^2	k_F (mmol/g·(L/mmol)1/n)	1/n	r^2
ZK06	1.90	0.8190	0.9980	1.6747	0.1521	0.8552
ZK09	2.42	0.1237	0.9963	2.2096	0.1185	0.9222

4. Discussion

The high adsorption capacity of zeolites results from their low density, high porosity, high crystallinity (structure stability), and uniform-sized channels [22, 23]. Choi and Lee

[24] estimated the maximum crystallinity of a Na-A zeolite hydrothermally synthesized using CFA to be less than 60%, and the results of Sr^{2+} adsorption experiments confirmed that the optimal q_m value was 1.51 mmol/g. Moreover, comparing the q_m for Sr^{2+} of Na-A zeolites synthesized with high crystallinity under various conditions of synthesis [25-27] and the values of 1.90 mmol/g for ZK06 and 2.42 mmol/g for ZK09 obtained in this study, it was found that they had higher adsorption capacities compared to those reported in previous studies. Therefore, limitations in terms of crystallinity and ion adsorption capacity can be resolved by synthesizing Na-A zeolites using eco-friendly and low-cost natural minerals.

Under conditions where Sr and Ca ions coexist, the adsorption capacity of Sr obtained using a commercial Na-A zeolite tended to decrease by 31.8% to 1.2 mmol/g, when compared to 1.76 mmol/g obtained in an aqueous solution with single Sr^{2+}. However, even when Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+} were present in the solution, the selectivity for Sr^{2+} by the adsorption of Na-A zeolite was higher than that of other ions [28].

5. Conclusions

Na-A zeolites synthesized from kaolin were used as adsorbents for removing radioactive strontium from aqueous solutions. The experimental adsorption data for Sr^{2+} exhibited q_m values of 1.90 and 2.42 mmol/g for the synthesized zeolites having NaOH/kaolin mass ratios of 0.6 and 0.9, respectively, and the Langmuir isotherm model suitably described the adsorption isotherm characteristics of the adsorbents. Based on these q_m values, ZK06 and ZK09 were evaluated to have adsorption capacities of approximately 73.6% and 93.4%, respectively, compared with the commercial Na-A zeolite. Overall, synthesized zeolites from natural inorganic materials using the fusion/hydrothermal method can be used as eco-friendly adsorbents to remove radioactive nuclides.

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References

1. Fesenko, S.; Isamov, N.; Barnett, C.L.; Beresford, N.A.; Howard, B.J.; Sanzharova, N.; Fesenko, E. Review of Russian language studies on radionuclide behaviour in agricultural animals: biological half-lives. *J. Environ. Radioact.* **2015**, *142*, 136–151. DOI:10.1016/j.jenvrad.2015.01.015.
2. Choi, J.-H.; Lee, C.-H. Evaluation of Sr and Cs ions adsorption capacities with zeolitic materials synthesized from various mass ratios of NaOH to coal fly ash. *Environmental Engineering Research*. **2022**, *27*, 200662. DOI:10.4491/eer.2020.662.
3. Rahman, R.O.A.; Ibrahim, H.A.; Hanafy, M.; Monem, N.M.A. Assessment of synthetic zeolite Na A–X as sorbing barrier for strontium in a radioactive disposal facility. *Chemical Engineering Journal*. **2010**, *157*, 100–112. DOI:10.1016/j.cej.2009.10.057.
4. Howard, E.B.; Clarke, W.J. Induction of hematopoietic neoplasms in miniature swine by chronic feeding of strontium-90. **1970**, *44*, 21–38.
5. Behrens, E.A.; Sylvester, P.; Clearfield, A. Assessment of a sodium nonatitanate and pharmacosiderite-type ion exchangers for strontium and cesium removal from DOE waste simulants. **1998**, *32*, 101–107.
6. Merceille, A.; Weinzaepfel, E.; Barré, Y.; Grandjean, A. The sorption behaviour of synthetic sodium nonatitanate and zeolite A for removing radioactive strontium from aqueous wastes. *Sep. Purif. Technol.* **2012**, *96*, 81–88.
7. Mustafa, Y.A.; Zaiter, M.J. Treatment of radioactive liquid waste (Co-60) by sorption on zeolite Na-A prepared from Iraqi kaolin. *J. Hazard. Mater.* **2011**, *196*, 228–233. DOI:10.1016/j.jhazmat.2011.09.013.
8. Kwon, S.; Choi, Y.; Singh, B.K.; Na, K. Selective and rapid capture of Sr2+ with LTA zeolites: Effect of crystal sizes and mesoporosity. *Appl. Surf. Sci*. **2020**, 506, 145029. DOI: 10.1016/j.apsusc.2019.145029.
9. Huang, Y.-H.; Wu, Y.-C. Highly efficient adsorption of Sr2+ and Co2+ ions by ambient prepared alkali activated metakaolin. *Polymers*. **2022**, 14, 992. DOI: 10.3390/polym14050992.

10. Khaleque, A.; Alam, M.M.; Hoque, M.; Mondal, S.; Haider, J.B.; Xu, B.; Johir, M.; Karmakar, A.K.; Zhou, J.; Ahmed, M.B. Zeolite synthesis from low-cost materials and environmental applications: A review. *Environ. Adv*. **2020**, 2, 100019. DOI: 10.1016/j.envadv.2020.100019.
11. Sazali, N.; Harun, Z. One hot of the hydrothermal route for the synthesis of zeolite LTA using kaolin. *J. Inorg. Organomet. Polym. Mater*. **2022**, 32, 3508-3520. DOI: 10.1007/s10904-022-02369-y.
12. Smičiklas, I.; Dimović, S.; Plećaš, I. Removal of Cs1+, Sr2+ and Co2+ from aqueous solutions by adsorption on natural clinoptilolite. **2007**, *35*, 139–144.
13. El-Kamash, A.M. Evaluation of zeolite A for the sorptive removal of Cs+ and Sr2+ ions from aqueous solutions using batch and fixed bed column operations. *J. Hazard. Mater.* **2008**, *151*, 432–445. DOI:10.1016/j.jhazmat.2007.06.009.
14. Lee, C.-H.; Park, J.-M.; Lee, M.-G. Adsorption characteristics of Sr(II) and Cs(I) ions by zeolite synthesized from coal fly ash. *Journal of Environmental Science International*. **2014**, *23*, 1987–1998. DOI:10.5322/JESI.2014.23.12.1987.
15. Lim, W.-R.; Lee, C.-H.; Hamm, S.-Y. Physics. Synthesis and characteristics of Na-A zeolite from natural kaolin in Korea. **2021**, *261*, 124230.
16. Anuwattana, R.; Khummongkol, P. Conventional hydrothermal synthesis of Na-A zeolite from cupola slag and aluminum sludge. *J. Hazard. Mater.* **2009**, *166*, 227–232. DOI:10.1016/j.jhazmat.2008.11.020.
17. Su, S.; Ma, H.; Chuan, X. Hydrothermal synthesis of zeolite A from K-feldspar and its crystallization mechanism. *Advanced Powder Technology*. **2016**, *27*, 139–144. DOI:10.1016/j.apt.2015.11.011.
18. Lagergren, S. Zur theorie der sogenannten adsorption geloster stoffe. **1898**, *24*, 1–39.
19. Langmuir, I. The adsorption of gases on plane surfaces of glass, mica and platinum. *J. Am. Chem. Soc.* **1918**, *40*, 1361–1403. DOI:10.1021/ja02242a004.
20. Freundlich, H. Over the adsorption in solution. **1906**, *57*, 1100–1107.
21. Murukutti, M.K.; Jena, H. Synthesis of nano-crystalline zeolite-A and zeolite-X from Indian coal fly ash, its characterization and performance evaluation for the removal of Cs+ and Sr2+ from simulated nuclear waste. *J. Hazard. Mater.* **2022**, *423*, 127085. DOI:10.1016/j.jhazmat.2021.127085.
22. Ren, X.; Xiao, L.; Qu, R.; Liu, S.; Ye, D.; Song, H.; Wu, W.; Zheng, C.; Wu, X.; Gao, X. Synthesis and characterization of a single phase zeolite A using coal fly ash. *RSC Adv.* **2018**, *8*, 42200–42209. DOI:10.1039/c8ra09215j.
23. Shichalin, O.O.; Papynov, E.K.; Ivanov, N.P.; Balanov, M.I.; Dran'kov, A.N.; Shkuratov, A.L.; Zarubina, N.V.; Fedorets, A.N.; Mayorov, V.Y.; Lembikov, A.O.; et al. Study of adsorption and immobilization of Cs+, Sr2+, Co2+, Pb2+, La3+ ions on Na-faujasite zeolite transformed in solid state matrices. *Separation and Purification Technology*. **2024**, 332, 125662. DOI:10.1016/j.seppur.2023.125662.
24. Choi, J.-H.; Lee, C.-H. Comparison of Cs and Sr Ion adsorption capacities with crystallinity of zeolitic materials synthesized from coal fly ash under low-alkaline conditions. *J. Environ. Sci. Int.* **2022**, *31*, 171–180. DOI:10.5322/JESI.2022.31.2.171.
25. Kumar, M.M.; Irshad, K.; Jena, H. Removal of Cs+ and Sr2+ ions from simulated radioactive waste solutions using zeolite-A synthesized from kaolin and their structural stability at high pressures. *Microporous Mesoporous Mater.* **2021**, *312*, 110773.
26. Merceille, A.; Weinzaepfel, E.; Barré, Y.; Grandjean, A. The sorption behaviour of synthetic sodium nonatitanate and zeolite A for removing radioactive strontium from aqueous wastes. *Sep. Purif. Technol.* **2012**, *96*, 81–88.
27. Lee, M.-G.; Kam, S.-K.; Lee, C.-H. Kinetic and isothermal adsorption properties of strontium and cesium ions by zeolitic materials synthesized from Jeju volcanic rocks. *Environmental Engineering Research*. **2021**, *26*, 200127. DOI:10.4491/eer.2020.127.
28. Lee, C.-H.; Park, J.-M.; Lee, M.-G. Competitive adsorption in binary solution with different mole ratio of Sr and Cs by zeolite A: Adsorption isotherm and kinetics. *Journal of Environmental Science International*. **2015**, 24, 151-162. DOI: 10.5322/JESI.2015.24.2.151.

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Removal of strontium ions from aqueous solution using Na-A zeolites synthesized from kaolin

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