DONG THAP UNIVERSITY JOURNAL OF SCIENCE
Tạp chí Khoa học Đại học Đồng Tháp
Natural Sciences Issue
ISSN 0866-7675 | e-ISSN 2815-567X

DOI: https://doi.org/10.52714/dthu.14.5.2025.1531

UTILIZING SILICA FROM RICE HUSK ASH TO SYNTHESIZE NaX ZEOLITE FOR ADSORBING Cr(VI) IONS FROM WATER

Luong Huynh Vu Thanh[1,2*] and Le Thanh Phu[2],
Nguyen Ngoc Yen[2,3], and Pham Duy Toan[3]

[1]Faculty of Chemical Engineering, Can Tho University, Vietnam
[2]Applied Chemical Engineering Lab, Can Tho University, Vietnam
[3]Department of Health Sciences, Can Tho University, Vietnam
[*]Corresponding author, Email: lhvthanh@ctu.edu.vn

Article history
Received: 03/3/2025; Received in revised form: 25/3/2025; Accepted: 01/4/2025

Abstract

This study aimed to use rice husk ash (RHA) as an agricultural by-product combined with heat treatment to recover silica and synthesize zeolite NaX through a hydrothermal method, optimizing the synthesis conditions. The molar ratio of reactants used in the synthesis was $4.2Na_2O:Al_2O_3:3SiO_2:18H_2O$*, with an aging time of 24 hours at room temperature and a crystallization time of 6 hours at 100°C. The adsorption of Cr(VI) ions in solution was optimized under conditions of pH 4.0, an initial Cr(VI) concentration of 120 mg/L, and a 30-minute adsorption time. The properties of the synthesized materials were characterized by X-ray diffraction (XRD) to identify characteristic diffraction peaks, and scanning electron microscopy (SEM) showed that the zeolite NaX had an average diameter of 113.16±0.12 nm. The study assessed the first-order and second-order adsorption kinetic models, as well as the Langmuir, Freundlich, and Dubinin-Radushkevich adsorption isotherms. Under the kinetic models, the adsorption of Cr(VI) ions onto the zeolite NaX followed the Langmuir isotherm model, with second-order kinetics and physical adsorption.*

Keywords: *Adsorbent, adsorption, hexavalent chromium ions, NaX zeolite, rice husk ash.*

Cite: Luong, H. V. T., Le, T. P., Nguyen, N. Y., & Pham, D. T. (2025). Utilizing silica from rice husk ash to synthesize nax zeolite for adsorbing Cr(VI) ions from water. *Dong Thap University Journal of Science*, *14*(5), 98-108. https://doi.org/10.52714/dthu.14.5.2025.1531

TẬN DỤNG NGUỒN SILICA TỪ TRO TRẤU TỔNG HỢP ZEOLITE NaX ĐỂ HẤP PHỤ ION Cr(VI) TRONG NƯỚC

Lương Huỳnh Vủ Thanh[1,2*] **và Lê Thành Phú**[2],
Nguyễn Ngọc Yến[2,3] **và Phạm Duy Toàn**[3]

[1]*Khoa Kỹ thuật hoá học, Trường Đại học Cần Thơ, Việt Nam*
[2]*Phòng thí nghiệm Ứng dụng kỹ thuật hoá học, Trường Đại học Cần Thơ, Việt Nam*
[3]*Bộ môn Khoa học sức khoẻ, Trường Đại học Cần Thơ, Việt Nam*
[*]*Tác giả liên hệ, Email: lhvthanh@ctu.edu.vn*

Lịch sử bài báo
Ngày nhận: 03/3/2025; Ngày nhận chỉnh sửa: 25/3/2025; Ngày duyệt đăng: 01/4/2025

Tóm tắt

Nghiên cứu này nhằm mục đích sử dụng tro trấu (RHA) như một phụ phẩm từ nông nghiệp kết hợp với xử lý nhiệt để thu hồi silica và tổng hợp zeolite NaX thông qua phương pháp thủy nhiệt, tối ưu hóa các điều kiện tổng hợp. Tỷ lệ mol của các chất phản ứng trong tổng hợp là 4,2Na_2O:Al_2O_3:3SiO_2:18H_2O, thời gian lão hóa là 24 giờ ở nhiệt độ phòng và thời gian tinh thể hóa là 6 giờ ở 100°C. Quá trình hấp phụ ion Cr(VI) trong dung dịch được tối ưu hóa dưới các điều kiện pH 4,0, nồng độ ban đầu của ion Cr(VI) là 120 mg/L và thời gian hấp phụ là 30 phút. Các đặc tính của vật liệu tổng hợp đã được xác định bằng phương pháp nhiễu xạ tia X (XRD) để xác định các đỉnh nhiễu xạ đặc trưng, và kính hiển vi điện tử quét (SEM) cho thấy zeolite NaX có đường kính trung bình là 113,16±0,12 nm. Nghiên cứu đánh giá các mô hình động học hấp phụ bậc nhất và bậc hai, cũng như các mô hình đẳng nhiệt hấp phụ Langmuir, Freundlich và Dubinin-Radushkevich. Theo các mô hình động học, quá trình hấp phụ ion Cr(VI) trên zeolite NaX tuân theo mô hình đẳng nhiệt Langmuir, với động học bậc hai và hấp phụ vật lý.

Từ khóa: *Hấp phụ, ion Cr(VI), tro trấu, zeolite NaX, vật liệu hấp phụ.*

1. Introduction

In recent years, environmental pollution in Vietnam and worldwide has been significantly concerned. Especially, water pollution has been and continues to worsen. Water environment is considered the source of life for all organisms, and clean water is not infinite, yet it is being heavily impacted by the development of various industries, including food processing, plant protection and pesticides, metallurgy, rubber, and paint. In particular, the metallurgy and electroplating industries are among the biggest challenges in wastewater treatment due to heavy metal pollution (Saleg et al., 2022). Some heavy metals include Chromium (Cr), Lead (Pb), Arsenic (As), Cadmium (Cd), Nickel (Ni), and others. Among them, Cr(VI) is an extremely toxic metal ion used in various industries such as tanning, stainless steel production, and electroplating (Khatun et al., 2022). When Cr(VI) ions are released into the environment, they significantly affect the health of organisms and humans, causing lung cancer, skin damage, liver and kidney damage, or digestive issues (Saleg et al., 2022). Therefore, finding an effective method to remove Cr(VI) ions from wastewater is crucial. Many methods have been used to remove Cr(VI) ions from aqueous solutions, including adsorption, ion exchange, chemical reduction, membrane filtration, with adsorption being one of the most popular techniques, attracting many researchers due to its simplicity, low cost, reliability, and high efficiency (Miretzky & Cirelli, 2010). In the adsorption process, the adsorbent plays a vital role in removing pollutants (Miretzky & Cirelli, 2010; Rathi & Kumar, 2021). Therefore, finding a material being able to remove heavy metal ions and cost-effective is an urgent requirement.

Currently, there have been many studies applying materials synthesized from agricultural by-products for the adsorption and treatment of water pollution. Particularly, zeolites synthesized from rice husk ash (RHA) show potential for application in treating pollutants in the water environment. (Ngoan et al., 2025). Zeolite is an inorganic material with a microporous structure and uniform size, which has been widely developed worldwide. The structure of zeolite consists of a network of tetrahedral $[SiO_4]_4^-$ and $[AlO4]_5^-$ units (Bensafi et al., 2023). These tetrahedra are linked together by oxygen bridges to form an open structure with empty cavities, making zeolite suitable for applications in adsorption, ion exchange, and catalysis (Bensafi et al., 2023; Ngoan et al., 2025). Among the various types of zeolite synthesized, NaX zeolite, belonging to the FAU family with large pore sizes (about 8 Å), is highly effective in adsorbing organic dyes, gases, or heavy metals (Mirzaei et al., 2020). NaX zeolite can be synthesized from commercial chemicals, natural mineral sources, or industrial and agricultural by-products such as diatomite, kaolin, fly ash, and RHA (Cao et al., 2023). Notably, a study by Akinjokun et al. (2024) synthesized NaX zeolite from rice husk ash, with the resulting zeolite having a size of about 72 nm. The structural characteristics and specific surface area were evaluated using XRD and BET analysis methods, and its application was tested in the adsorption of Cu^{2+} and Ni^{2+} ions in aqueous environments. Another study by Masoud et al. (2022) combined Humic acid and NaX zeolite synthesized from silica derived from rice husk ash. The structural characteristics were confirmed through XRD, FT-IR, and SEM methods, and the application was focused on the treatment of Cd^{2+} and Pb^{2+} ions. However, the use of NaX zeolite as an adsorbent for treating Cr(VI) ions in water and studies on the kinetics and isotherms of Cr(VI) ion adsorption on zeolite NaX have not been widely researched.

In this study, NaX zeolite was synthesized from rice husk ash (RHA) replacing commercial silica sources to synthesize highly economical adsorbent materials capable of effectively removing Cr(VI) metal ions in aqueous solutions. The study explored the influence of factors such as pH, initial concentration of Cr(VI) ions (mg/L), adsorption time (minutes), and adsorbent dose (mg). Based on the experimental results, kinetic and isothermal models of the Cr(VI) ion adsorption process on NaX zeolite were investigated widely.

2. Research methods

2.1. Materials

Rice husk ash (RHA) was collected from the Duc An brick kiln, My Xuong commune, Cao Lanh district, Dong Thap province. The chemicals like hydrochloric acid (HCl), sodium hydroxide (NaOH), potassium dichromate ($K_2Cr_2O_7$), and sodium aluminate ($NaAlO_2$) were supplied by Xilong Chemical Company. The chemicals were used without further purification, and distilled water was used as the solvent in this study.

2.2. Synthesis of NaX zeolite from RHA

NaX zeolite was synthesized from rice husk ash (RHA) as used by Wang et al. (2018), with some modifications to suit laboratory conditions. First, RHA was soaked in a 1 M H_2SO_4 solution at a ratio of RHA:acid solution 1:10 (w/v) for 24 hours. The solid phase was then filtered, washed to neutral pH, dried, and calcined at 800°C for 1.5 hours. After the pre-treatment process, the RHA was subjected to a solid-liquid extraction to obtain SiO_2 using a 4 M NaOH solution, with a solid-to-liquid ratio of 1:10 (w/v), stirred at 200 rpm, and a reaction temperature of 80°C. After the reaction, the filtrate containing Na_2SiO_3 was collected.

Synthesis of zeolite: 15 mL of 1 M Na_2SiO_3 solution was added to a Erlenmeyer flask, followed by 5 mL of 4 M NaOH solution, and stirred well. Then, 10 mL of 1 M $NaAlO_2$ solution was slowly added and stirred thoroughly. The mixture was stirred on a magnetic stirrer at 400 rpm for 2 hours. After that, aging was carried out for 24 hours at room temperature, and crystallization was done in a Teflon container at 100°C for 6 hours. After crystallization, the sample was filtered, washed several times with distilled water, and dried at 60°C for 12 hours.

2.3. Characterizations of materials

This study applied the X-ray diffraction (XRD) device model D8-Advance from Bruker – Germany, measuring samples in the 2θ range from 10 to 80 degrees to evaluate the characteristic crystalline structure of NaX zeolite. The high-resolution scanning electron microscope (FE-SEM-4800) model S4800 from Hitachi was used with the following measurement conditions: magnifications of 5000 and 1000; secondary voltage of 10.0 kV. This analysis helps determine the morphological characteristics of the NaX zeolite material. X-ray fluorescence spectroscopy (XRF, Horiba MESA-50) was used to assess the chemical composition of RHA. Inductively coupled plasma optical emission spectrometry (ICP-OES, ICAP7400DUO-SPH006) was used to measure the SiO_2 content in the Na_2SiO_3 solution. The Quantachrome gas adsorption analyzer (NOVA: 4000e) was used to evaluate the specific surface area, pore volume, and pore size of NaX zeolite.

The relative intensities of the peaks were then used to determine the relative crystallinity of each sample. Under American Society for Testing and Materials (ASTM) standard, the crystallinity percent (%) was determined using equation (1) (Berger et al., 2005):

$$\text{Crystallinity (\%)} = \frac{\text{Intensity of peak (sample)}}{\text{Intensity of peak (reference)}} \text{ x } 100 \qquad (1)$$

The surface charge of NaX zeolite was determined by the salt method (Khan & Sarwar, 2007). First, 20 mL of 0.1 M KCl solution was added to Erlenmeyer flasks, and the pH was adjusted from 2 to 11 using 0.01 M NaOH and 0.01 M HCl. Then, 0.1 g of NaX zeolite was added to the pH-adjusted Erlenmeyer flasks and shaken at 150 rpm for 24 hours. After 24 hours, the pH of the solution was measured. The difference in pH between the solution before and after 24 hours indicates the surface charge of the zeolite at different pH values and the point of zero charge of the zeolite (pH_{pzc}).

2.4. Adsorptionexperiments of Cr(VI) from aqueous solution

To investigate the parameters affecting the Cr(VI) adsorption process, the following parameters were studied pH (2-6), adsorption time (15-90 minutes), and initial Cr(VI) concentration (80-120 mg/L). These parameters were investigated sequentially.

Adsorption procedure: 100 mL of a solution containing Cr(VI) ions with adjusted pH and concentration subject to the experimental conditions was added to each Erlenmeyer flask. 0.1 g of the material was weighed and added to the prepared Erlenmeyer flasks, then shaken at 150 rpm. After the adsorption process, centrifugation was performed at 10,000 rpm to collect the supernatant. The concentration of Cr(VI) ions was analyzed using a UV-Vis spectrophotometer at the maximum absorption wavelength of 540 nm. The adsorption efficiency and adsorption capacity were determined using the following two formulas:

$$\mathrm{H}(\%) = \frac{\mathrm{C_o} - \mathrm{C_c}}{\mathrm{C_o}} \qquad (2)$$

$$\mathrm{q_c}(\mathrm{mg/g}) = \frac{(\mathrm{C_o} - \mathrm{C_c}).\mathrm{V}}{\mathrm{m}} \qquad (3)$$

where, Co is the initial concentration (mg/L) and Cc is the concentration at equilibrium (mg/L). V is the volume of the solution (L) and m is the mass of the adsorbent (g).

This study used the linear kinetic models of the first-order and second-order pseudo-kinetic models. The linear adsorption isotherm models of Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich were developed based on the experimental results.

3. Results and discussion

3.1. Contents of RHA with and without pretreatment

After undergoing the acid pre-treatment and calcination process, many other metal oxide components were removed, such as Cr_2O_3, which decreased from 0.021% to 0.008%, MgO from 0.163% to 0.014%, and Fe_2O_3 from 0.137% to 0.021%. This helped increase the SiO2 content in rice husk ash from 87.67% to 93.12%. The main purpose of this process is to clean the rice husk ash and reduce the content of other metal oxides that could affect the zeolite synthesis process (Ngoan et al., 2025).

Table 1. Oxide content of RHA with and without pre-treatment

Content (%)	**Oxides**								
	SiO_2	**Cr_2O_3**	**MgO**	**Al_2O_3**	**P_2O_5**	**K_2O**	**CaO**	**Fe_2O_3**	**others**
Without pre-treatment	87.670	0.021	0.163	0.219	0.137	2.324	0.815	0.137	8.514
With pre-treatment	93.120	0.008	0.014	0.221	0.094	2.678	0.733	0.021	8.514

3.2. Characteristics of NaX zeolite

From the X-ray diffraction (XRD) results in Figure 1(A), it can be seen that at the positions 2θ = 6°, 10.5°, 17°, 26.5°, 30.5°, and 35° of the sample, characteristic diffraction peaks for the structure of NaX zeolite appear, which is consistent with the standard card and with previously published works (Mirzaei et al., 2020; Akinjokun et al., 2024; Masoud et al., 2024). From the XRD results of the NaX zeolite, the crystallinity value was calculated to be 76.14%. The characteristic morphology of NaX zeolite was evaluated using field emission scanning electron microscopy (FE-SEM). Figure 1(B) shows that the NaX zeolite crystals were well crystallized, displaying typical octahedral structures with relatively uniform size and morphology. These results are consistent with previously published works (Wang et al., 2018; Akinjokun et al., 2024).

The specific surface area and pore diameter of the synthesized NaX zeolite were evaluated using the BET equation in Figure 1(C) through the nitrogen adsorption/desorption isotherm method. The results showed that the specific surface area and pore diameter of the zeolite were 28.91 m²/g and 28 Å, respectively. The large pore size and specific surface area of zeolite help the material easily interact well with the adsorbate, contributing to increased adsorption efficiency. Additionally, with its large pore sizes, zeolite can adsorb even larger molecules, thus enhancing the adsorption efficiency. Its large pore size is due to the hydrothermal crystallization process at 100°C, where the evaporation of water forms gas bubbles that create the porous structure in the material. Furthermore, when calculating according to BET, the pore structure is assumed to be cylindrical; however, in reality, the pores are close to cylindrical in shape, which leads to errors (Wang et al., 2018; Bensafi et al., 2023).

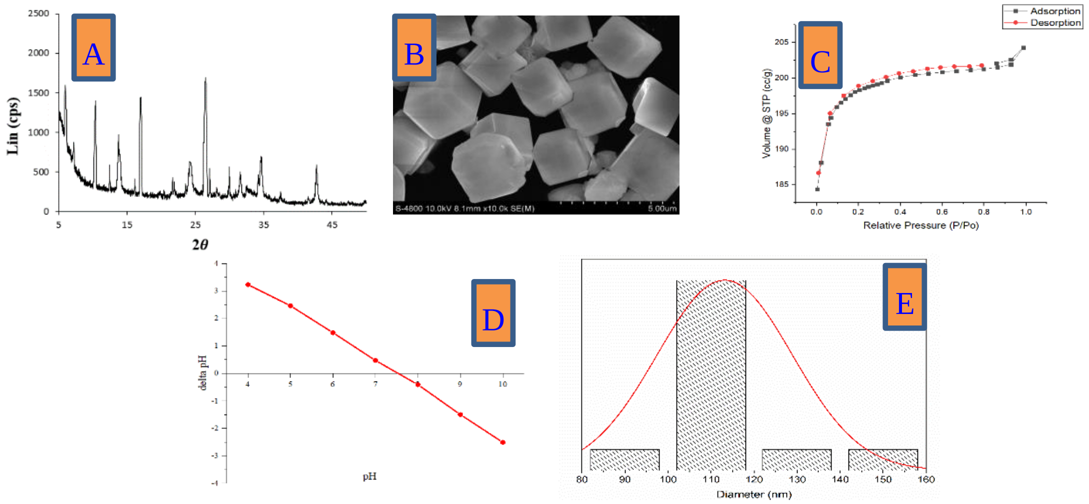

Figure 1. The characteristics of NaX zeolite: (A) XRD, (B) FE-SEM, (C) N_2 adsorption-desorption isotherms, (D) pH_{pzc}, (E) particle size distribution.

The surface charge of the material particles was evaluated, and the results shown in Figure 1(D) demonstrate the change in the surface charge of NaX zeolite from positive to negative as the pH increases. From Figure 1(D), it can be observed that the point of zero charge (pH_{pzc}) of NaX zeolite is 7.5. The material's surface will be positively charged when pH < 7.5 and negatively charged when pH > 7.5. Therefore, it can be predicted that at pH < 7.5, the material will adsorb anions well. In this study, NaX zeolite effectively adsorbs Cr(VI) ions from the solution.

The particle size distribution of NaX zeolite is shown in Figure 1(E). It can be observed that the size of the successfully synthesized NaX zeolite is concentrated around 107 nm – 114 nm, with an average size of 113.16±0.12 nm.

3.3. Adsorption of Cr(VI) from aqueous solution using NaX zeolite

The factors influencing the adsorption process, including pH, initial concentration of Cr(VI) ions, and adsorption time, have been studied and evaluated. The results of the effects of these factors on the adsorption of Cr(VI) ions in aqueous solution using NaX zeolite are shown in Figure 2.

In Figure 2(A), it can be seen that the adsorption capacity varies; however, the difference is not significant in the pH range from 2 to 4 (the adsorption capacity fluctuates between 41.13 – 42.83 mg/g). When the pH exceeds 4, the adsorption capacity starts to decrease slightly and then drops sharply as the pH increases to 6 (from 41.80 to 40.18 mg/g, and then decreases to 20.17 mg/g, a 49.80% decrease). By comparing the adsorption capacity and removal efficiency, it can be observed that at a pH of 3.0, zeolite exhibits the strongest adsorption capability, with the highest adsorption capacity of 42.83 mg/g and an efficiency of 85.67%. This can be explained by the fact that the adsorption process of zeolite is competed for by H^+ and OH^- ions on the adsorption surface. However, in an acidic environment, the zeolite predominantly adsorbs anions (as predicted from the pH_{pzc} shown in Figure 1(D)), so despite a high concentration of H^+ ions, the zeolite still adsorbs Cr(VI) effectively. Additionally, from Figure 2(A), it can be seen that at pH 3.0, Cr(VI) exists as dichromate ions ($Cr_2O_7^{2-}$) and chromate ions ($HCrO_4^-$), which are small anions that are easily adsorbed. At pH 2.0 and pH 4.0, Cr(VI) gradually transitions into chromic acid (H_2CrO_4), a large cyclic anhydride, which is difficult to adsorb (Ngoan et al., 2025). The adsorption capacity remains nearly unchanged between pH 2.0 and 4.0 (ranging from 41.13 – 42.83 mg/g) and reaches its highest value at pH 3.0 with a capacity of 42.83 mg/g. This can be explained as follows: in the pH range from 2.0 to 4.0, Cr(VI) changes from dichromate ($Cr_2O_7^{2-}$) and chromate ($HCrO_4^-$) to chromic acid (H_2CrO_4), but this change is minimal, so the adsorption capacity of zeolite remains relatively constant (only fluctuating between 41.13 – 42.83 mg/g). From pH 5.0 to pH 6.0, dichromate ($Cr_2O_7^{2-}$) and chromate ($HCrO_4^-$) almost completely convert to CrO_4^{2-}, which is difficult to adsorb, leading to a large decrease in adsorption capacity (from 40.18 to only 20.17 mg/g) (Chowdhury et al., 2020).

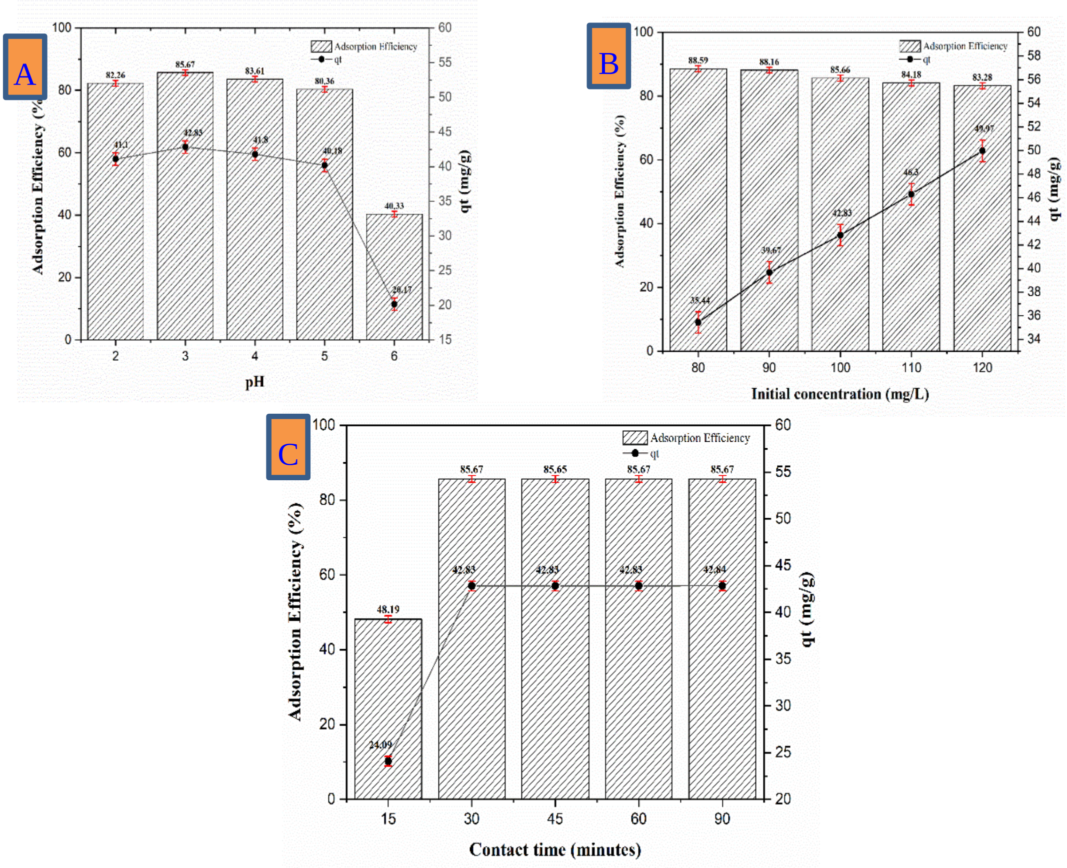

Figure 2. Effects of (A) pH, (B) initial concentration, (C) contact time on Cr(VI) ion adsorption using NaX zeolite.

The influence of the initial Cr(VI) ion concentration on the adsorption process using NaX zeolite is shown in Figure 2(B). From the results presented in Figure 2(b), it can be observed that the efficiency gradually decreases as the initial concentration of the investigated solution increases from 80 mg/L to 120 mg/L. However, this change is not significant; in other words, the process efficiency remains stable (changing from 88.59% to 83.28%). The reason for this decrease in adsorption efficiency can be explained by the fact that as the concentration of Cr(VI) ions increases, these ions will quickly occupy the adsorption sites on the surface of the zeolite. This causes shielding, making it difficult for the unadsorbed Cr(VI) ions to bind to the remaining adsorption sites and diffuse into the pores of the material (Zeng et al., 2010).

The effect of adsorption time is shown in Figure 2(C). From the survey results, it is observed that as the adsorption time increases, the efficiency and adsorption capacity gradually increase. At 15 minutes, the zeolite achieves optimal adsorption of Cr(VI) with an adsorption efficiency of 48.19% and a capacity of 24.09 mg/g. When the adsorption time is increased to 30 minutes, the adsorption efficiency suddenly increases to 85.67%, with a capacity of 42.83 mg/g. However, as the time continues to increase, the adsorption efficiency and capacity remain almost unchanged. This can be explained by the fact that the adsorption process reaches saturation at approximately 30 minutes, with most of the adsorption sites on the surface of NaX zeolite already saturated. Therefore, as the time increases further, the adsorption still increases, but not significantly, because once the sites are saturated, more time is needed for the Cr(VI) ions to diffuse into the pores (Zeng et al., 2010; Ngoan et al., 2025).

3.4. Kinetics, isotherm adsorption of Cr(VI) using NaX zeolite

The first-order and second-order kinetic models were developed based on the experimental results of the Cr(VI) ion adsorption process in aqueous media on the NaX zeolite, as shown in Figure 3.

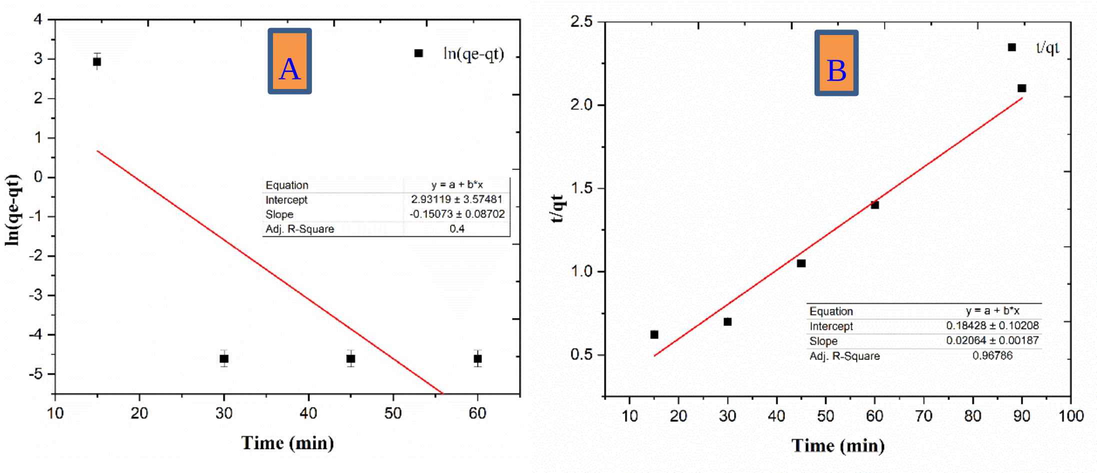

Figure 3. (A) first-order and (B) second-order kinetic models

Based on the results of the linear regression equations in Figures 3(A) and 3(B), the adsorption capacity, rate constants, and linear regression coefficients have been determined and presented in tables in Figure 3. The linear regression coefficient (R^2) for second-order models is high, indicating a strong agreement between the experimental results and the predicted values from the mathematical model. Comparing the R^2 values of the two equations shows that the second-order kinetic model has a higher R^2 value of 0.9678 and a rate constant $k_2 = 0.059$, compared to $R^2 = 0.4$ and $k_1 = 0.15$ for the first-order kinetic model. This suggests that the Cr(VI) ion adsorption process using NaX zeolite is more consistent with the second-order kinetic model. With a larger slope, the adsorption capacity decreases. If the time (t) is kept constant, a larger slope will make t/qt larger. Since qt is inversely proportional to t/qt, a smaller slope will increase the adsorption capacity and speed of the adsorbent (Le et al., 2024).

The adsorption isotherm is used to describe the distribution of Cr(VI) between the solid phase and the liquid phase under equilibrium conditions, as shown in Figure 4. When constructing the adsorption isotherm, the Langmuir, Freundlich, and Dubinin-Radushkevich isothermal models are applied to examine whether the adsorption mechanism is chemical or physical, and the linear equation for the curve is obtained as follows:

Langmuir: $y = 0.0114x + 0.2157$ với $R^2 = 0.9716$; $q_{max} = 87.64$ (mg/g); $k_L = 0.05$

Freundlich: $y = 0.084x – 0.1197$ với $R^2 = 0.878$; $n = 2.27$; $k_F = 2.88$

Dubinin-Raduskevich: $y = -18.322x + 4.2069$ với $R^2 = 0.9685$; $E = 0.1652$ (kJ/mol)

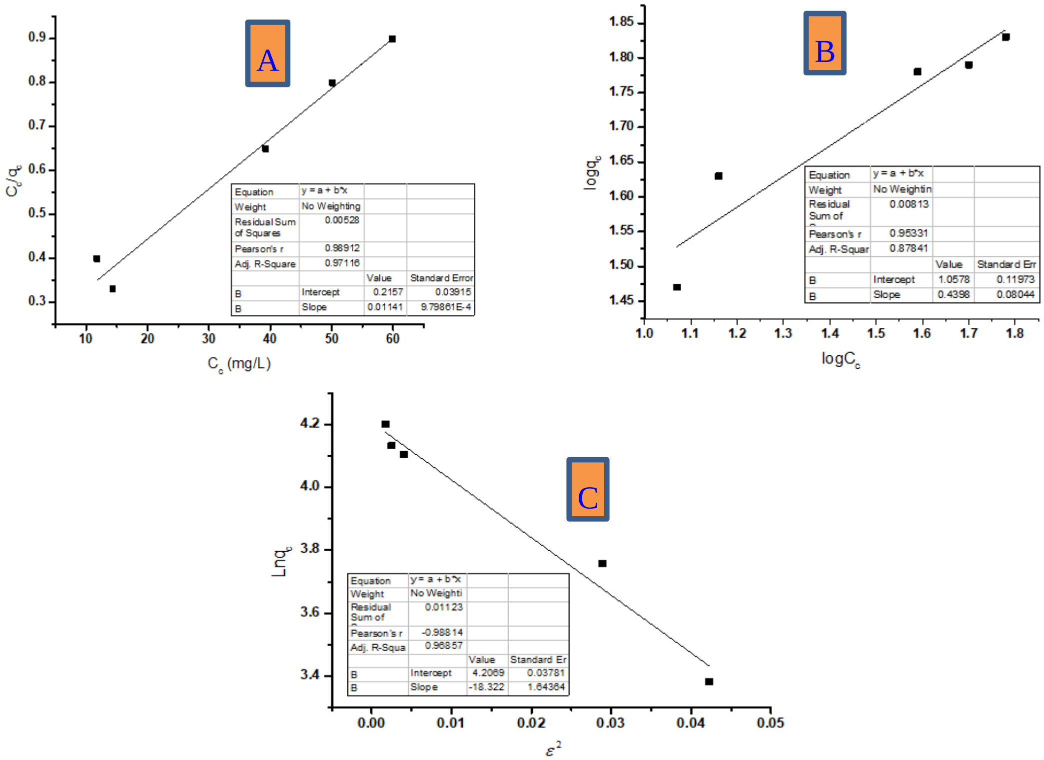

Figure 4. Adsorption isotherm models (A) Langmuir, (B) Freundlich, and (C) Dubinin-Raduskevich

Both the Langmuir and Freundlich isotherm models have linear regression coefficients higher than 0.8, indicating compatibility with the model. However, with $R^2 = 0.9716$, the Langmuir model has a higher linear regression coefficient, demonstrating its better fit for the Cr(VI) ion adsorption process on zeolite NaX material. Under the Langmuir model (with $R^2 = 0.878$), with $K = 0.05$ ($1.mg^{-1}$) within the range of $0 < K < 1$, it means the adsorption process is favorable and reversible. For the Dubinin-Radushkevich isothermal model, the calculated adsorption energy E is 0.1652 (kJ/mol) < 8 (kJ/mol), proving that the adsorption of Cr(VI) ions on the surface of zeolite NaX is a physical adsorption process (Ding et al., 2018).

3.5. Comparison with other adsorbents for Cr(VI) ions removal

The zeolite NaX synthesized from silicate recovered from rice husk ash was evaluated for its maximum Cr(VI) ions adsorption capacity (q_{max}) in aqueous solution and compared to other materials, with the results shown in Table 2.

From the data summarized in Table 2, it is evident that the adsorption capacity of Cr(VI) ions in the zeolite NaX material synthesized from rice husk ash-derived silica is relatively high when compared to other adsorbent materials sourced from biomass. Specifically, the zeolite NaX exhibits a calculated q_{max} value of 87.64 mg/g, which surpasses the 18.02 mg/g reported for crystalline hydrous titanium oxide (Debnath et al., 2008). Notably, the synthesis process of zeolite NaX in this study is more straightforward and cost-effective. Additionally, compared to biomass-derived materials such as coconut husk with a q_{max} value of 29 mg/g (Miretzky et al., 2010), zeolite NaX continues to demonstrate a higher Cr(VI) ion adsorption capacity. Although hybrid polysaccharide beads composed of alginate with poly(4-vinyl-N-pentyl pyridinium bromide), which show a q_{max} value of 156.6 mg/g (de Carvalho et al., 2018), exhibit superior adsorption performance, zeolite NaX still offers notable advantages in terms of cost-effectiveness and practical application deployment, particularly when synthesized from silica recovered from rice husk ash.

Table 2. Comparison adsorption capacities maximum calculated of Cr(VI) by zeolite NaX with other adsorbents

Adsorbent	Calculated q_{max} (mg/g)	References
Coconut husk	29	Miretzky et al., 2010
Crystalline hydrous titanium oxide	18.02	Debnath et al., 2008
Hybrid polysaccharide beads **(**Alginate with poly(4-vinyl-*n*-pentyl pyridinium bromide)	156.6	de Carvalho et al., 2018
NaX zeolite from RHA	87.64	This study

4. Conclusion

This study successfully synthesized NaX zeolite from rice husk ash, and the material's structural and property characteristics were evaluated using modern analytical methods. XRD revealed the characteristic diffraction peaks of NaX zeolite, SEM showed the typical morphology of the material, and BET demonstrated that the synthesized NaX zeolite had a surface area of 28.91 m^2/g and a pore diameter of 28 Å. The material's pHpzc was found to be 7.5. The size of the synthesized NaX zeolite material ranged from 107 nm to 114 nm, with an average size of 113.16±0.12 nm. The results of applying NaX zeolite for the adsorption and treatment of Cr(VI) ions in water showed that the optimal conditions for the treatment process were pH 4, an initial concentration of 120 mg/L, and an adsorption time of 30 minutes. The experimental results for the Cr(VI) ion adsorption process in water using NaX zeolite were consistent with the Langmuir model, indicating that the adsorption process is reversible, favorable, and a physical adsorption process.

References

Akinjokun, A. I., Ogunfowokan, A. O., Ajao, J., Petrik, L. F., & Ojumu, T. V. (2024). Template-free conversion of rice husk silica into nano-zeolite X and its application in adsorption of heavy metal ions. *International Journal of Environmental Science Technology, 21*(2), 1949-1960. https://doi.org/10.1007/s13762-023-05076-4.

Bensafi, B., Chouat, N., & Djafri, F. (2023). The universal zeolite ZSM-5: Structure and synthesis strategies. A review. *Coordination Chemistry Reviews, 496*, 215397. https://doi.org/10.1016/j.ccr.2023.215397.

Berger, C., Gläser, R., Rakoczy, R. A., Weitkamp, J. (2005). The synthesis of large crystals of zeolite Y re-visited. Micropor. Mesoporo. Mater. 83, 333-344. https://doi.org/10.1016/j.micromeso.2005.04.009

Cao, C., Xuan, W., Yan, S., & Wang, Q. (2023). Zeolites synthesized from industrial and agricultural solid waste and their applications: A review. *Journal of Environmental Chemical Engineering, 11*(5), 110898. https://doi.org/10.1016/j.jece.2023.110898.

Chowdhury, A., Kumari, S., Khan, A. A., & Hussain, S. (2020). Selective removal of anionic dyes with exceptionally high adsorption capacity and removal of dichromate ($Cr_2O_7^{2-}$) anion using Ni-Co-S/CTAB nanocomposites and its adsorption mechanism. *Journal of Hazardous Materials, 385*, 121602. https://doi.org/10.1016/j.jhazmat.2019.121602.

Debnath, S., & Ghosh, U. C. (2008). Kinetics, isotherm and thermodynamics for Cr (III) and Cr (VI) adsorption from aqueous solutions by crystalline hydrous titanium oxide. *The Journal of Chemical Thermodynamics*, *40*(1), 67-77. https://doi.org/10.1016/j.jct.2007.05.014

de Carvalho, G. G. A., Kelmer, G. A., Fardim, P., Oliveira, P. V., & Petri, D. F. (2018). Hybrid polysaccharide beads for enhancing adsorption of Cr (VI) ions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *558*, 144-153. https://doi.org/10.1016/j.colsurfa.2018.08.053

Ding, R.D., Yun, Z. U., Zhou, C. H., Huan, W. A. N. G., Mo, Z. S., Qin, Y. C., ... & Song, L. J. (2018). Insight into the correlation between the effective adsorption sites and adsorption desulfurization performance of CuNaY zeolite. *Journal of Fuel Chemistry Technology, 46*(4), 451-458. https://doi.org/10.1016/S1872-5813(18)30020-3.

Khan, M.N., & Sarwar, A. (2007). Determination of points of zero charge of natural and treated adsorbents. *Surface Review Letters, 14*(03), 461-469. https://doi.org/10.1142/S0218625X07009517Cited

Khatun, J., Intekhab, A., & Dhak, D. (2022). Effect of uncontrolled fertilization and heavy metal toxicity associated with arsenic (As), lead (Pb) and cadmium (Cd), and possible remediation. *Toxicology, 477*, 153274. https://doi.org/10.1016/j.tox.2022.153274.

Le, T. P., Luong, H. V. T., Nguyen, H. N., Pham, T. K. T., Le, T. L. T., Tran, T. B. Q., & Ngo, T. N. M. (2024). Insight into adsorption-desorption of methylene blue in water using zeolite NaY: Kinetic, isotherm and thermodynamic approaches. *Results in Surfaces Interfaces, 16*, 100281. https://doi.org/10.1016/j.rsurfi.2024.100281.

Masoud, M. S., Zidan, A. A., El Zokm, G. M., Elsamra, R. M., & Okbah, M. A. (2024). Humic acid and nano-zeolite NaX as low cost and eco-friendly adsorbents for removal of Pb(II) and Cd(II) from water: characterization, kinetics, isotherms and thermodynamic studies. *Biomass Conversion Biorefinery, 14*(3), 3615-3632. https://doi.org/10.1007/s13399-022-02608-9.

Miretzky, P., & Cirelli, A. F. (2010). Cr (VI) and Cr (III) removal from aqueous solution by raw and modified lignocellulosic materials: a review. *Journal of Hazardous Materials, 180*(1-3), 1-19. https://doi.org/10.1016/j.jhazmat.2010.04.060.

Mirzaei, D., Zabardasti, A., Mansourpanah, Y., Sadeghi, M., & Farhadi, S. (2020). Efficacy of novel NaX/MgO–TiO_2 zeolite nanocomposite for the adsorption of methyl orange (MO) dye: Isotherm, kinetic and thermodynamic studies. *Journal of Inorganic Organometallic Polymers Materials 30*(6), 2067-2080. https://doi.org/10.1007/s10904-019-01369-9.

Ngoan, N. H., Thanh, L. H., Phu, L. T., Giao, D. H., & Mai, N. T. (2025). Improving copper ions adsorption using Ca-modified NaY zeolite synthesized from calcined rice husk ash. *Journal of Sol-Gel Science Technology, 113*, 438-449. https://doi.org/10.1007/s10971-024-06637-w.

Rathi, B. S., & Kumar, P. S. (2021). Application of adsorption process for effective removal of emerging contaminants from water and wastewater. *Environmental Pollution, 280*, 116995. https://doi.org/10.1016/j.envpol.2021.116995.

Saleh, T. A., Mustaqeem, M., & Khaled, M. (2022). Water treatment technologies in removing heavy metal ions from wastewater: A review. *Environmental Nanotechnology, Monitoring Management, 17*, 100617. https://doi.org/10.1016/j.enmm.2021.100617.

Wang, Y., Du, T., Jia, H., Qiu, Z., & Song, Y. (2018). Synthesis, characterization and CO_2 adsorption of NaA, NaX and NaZSM-5 from rice husk ash. *Solid State Sciences, 86*, 24-33. https://doi.org/10.1016/j.solidstatesciences.2018.10.003.

Zeng, Y., Woo, H., Lee, G., & Park, J. (2010). Adsorption of Cr (VI) on hexadecylpyridinium bromide (HDPB) modified natural zeolites. *Microporous Mesoporous Materials, 130*(1-3), 83-91. https://doi.org/10.1016/j.micromeso.2009.10.016.