

# Characterization and Application of Bayah Natural Zeolites for Ammonium Capture: Isotherm and Kinetic

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**Abstract.** The aim of this study is to characterize Bayah natural zeolites and tested for ammonium capture. Characterization of Bayah natural zeolites were performed by X-ray diffraction (XRD), scanning electron microscope (SEM), and nitrogen physisorption. The natural zeolites were identified as mordenite and clinoptilolite. Non-zeolitic phase appeared on the XRD pattern was quartz. The morphology of clinoptilolite and mordenite were observed as platy and needle shape in the SEM images, respectively. Major cations were  $K^+$  and  $Ca^{2+}$  which were determined by energy dispersive X-ray. Nitrogen isotherm physisorption suggested that the natural zeolites was typical of type IV isotherm. Pore size distribution were determined using Barrett, Joyner, and Halenda model with mesopore size 3-5 nm. Ammonium exchange on Bayah natural zeolites were conducted in a batch experiment by varying the particle sizes, time and mass loading. Non-linear least squared method was applied to fit the experimental data with various kinetic and isotherm models. The kinetic data was well fitted with the Elovich equation with error  $1.6 \times 10^{-4}$ . Isotherm adsorption of ammonium followed Langmuir-Vageler with error  $4 \times 10^{-2}$ .

## 1. Introduction

The world is facing food crisis because of the high population growth rate, particularly in developing countries like Indonesia. However, the agriculture area has been declining as it is converted for housing and factories. To make it worst, the food security depends on synthetic fertilizer in which the raw materials are derived from fossil materials, i.e., natural gas to produce synthesis gas (syngas) via steam reforming. The syngas then converted into ammonia through Haber-Bosch reaction over iron catalyst under high pressure and temperatures [1]. There is an urge to find a new path for nitrogen capture instead of the high demand energy and non-renewable fossil of the conventional method. Electrolysis of water using solar panel into syngas is one alternative to produce ammonia from renewable source. However, water electrolysis costs 2-3 more expensive than the conventional route [2]. Adsorption technology for ammonium capture is interesting because it needs low energy. The source of ammonium can be obtained in industrial and domestic wastewater, livestock dung, and agricultural residue. By utilizing waste ammonium sources, there are two benefits could be achieved. First, removal of ammonium in wastewater or other ammonium waste sources. Second, ammonium can be utilized as fertilizer.

There are some materials that could be utilized as sorbent for ammonium such as activated carbon and zeolites. Activated carbon are cheap and renewable, however ammonium removal selectivity is low. Natural zeolites are low cost materials that can be easily founded throughout the world. Natural clinoptilolite are the most famous natural zeolites type for ammonium capture. There are some investigations that reported the study of natural clinoptilolite, i.e., the effect of particle size, pH, ammonium concentration on the ammonium removal. Study of kinetic and isotherm adsorption of the clinoptilolite also could be easily found in the literature [3-5]. The clinoptilolite was also investigated for slow release fertilizer application [6]. Natural clinoptilolite was not only improved the nitrogen efficiency but also reduced water consumption in semi-arid area [7]. Adding natural zeolites in an anaerobic digester for wastewater processing improved the biogas production

significantly because ammonium as an inhibitor can be captured in the pore of natural zeolites [8, 9].

Indonesian natural zeolites are widely spread in the archipelago particularly along the ring of fire Indonesia. However, characterization, kinetic and equilibrium study of ammonium capture of Indonesian natural zeolites are rarely reported. The aim of this paper is to study the characteristics of Bayah natural zeolites and testing for ammonium capture, isotherm adsorption and kinetic analysis.

## 2. Material and Methods

### 2.1 Materials and chemical reagents

The natural zeolites were collected from the sedimentary bed in Pasir Gombong, Bayah, Indonesia. Analytical grade ammonium chloride (Merck), reagent Nessler (Hanna) and deionized water were used for ammonium adsorption testing.

### 2.2 Natural zeolites characterization

#### 2.2.1 X-ray diffraction.

X-ray diffractometer (XRD) pattern was obtained using a Shimadzu 7000 Maxima-X with a Cu-K $\alpha$ . Scan range was performed between 2 and 90° with scan speed 2°/min and sampling pitch 0.02°.

#### 2.2.2 Scanning electron microscope and energy dispersive x-ray.

Crystal morphology was studied by scanning electron microscope (SEM). Elemental composition of the natural zeolites were analyzed by energy dispersive x-ray (EDX). Both of analysis were performed using a Zeiss.

#### 2.2.3 Nitrogen adsorption-desorption.

The textural properties of the natural zeolites were determined using N<sub>2</sub> adsorption-desorption which was carried out using a Micromeritic Tristar II 3020. Prior to analysis, 0.16 g sample was degassed at 90 °C for 30 min and 350 °C for 360 min to remove water and gasses trapped inside the pores. Isotherm was recorded at liquid nitrogen bath temperature 77 K. Brunauer–Emmett–Teller (BET) model was used to calculate surface area. The micropore volume was determined by using t-plot method. The mesopore volume was obtained by subtracting the total pore volume from the micropore volume. Pore size distribution was calculated using Barrett, Joyner, and Halenda (BJH) method.

### 2.3 Natural zeolites testing for ammonium removal

The as received natural zeolites was crushed into size 0.84-2.0 mm (sample A), 6.3-9.5 mm (sample B) and 12.7-16 mm (sample C) to study the effect of particle size on ammonium capture. Ammonium solution 1000 ppm was prepared by dissolving 2.97 g NH<sub>4</sub>Cl in 1 L deionized water. Dilution procedure of the solution was performed to obtain 100 ppm ammonium solution. The NH<sub>4</sub><sup>+</sup> concentration in the solution was analyzed by colorimetry method (Hanna HI733). Natural zeolites weight of sample A was varied from 0.5 to 10 g with constant size. Volume of ammonium chloride solution was fixed 50 mL. Kinetic of ammonium removal over natural zeolites was studied by observing the concentration of ammonium in solution from 0 to 72 h over 10 g natural zeolites. Ammonium isotherm analysis was carried out at 72 h with mass of zeolites,  $m$ , varied from 0.5 to 3.5 g in a constant volume,  $V$ , 50 ml ammonium solution and constant ammonium concentration at 100 ppm. The amount of ammonium captured per mass of zeolites  $q$  [mg/g] was determined using Eq. 1 below.

$$q = \frac{(C_0 - C_e)V}{m} \quad (1)$$

where  $C_0$  is initial concentration of ammonium [mg/L] and  $C_e$  refers to equilibrium concentration of ammonium [mg/L].

Removal of ammonium efficiency was calculated by Eq. 2 as follows.

$$\text{Removal efficiency [\%]} = \frac{(C_0 - C_t)}{C_0} \times 100\% \quad (2)$$

## 2.4 Calculation

### 2.4.1 Kinetic data analysis.

Pseudo-first-order or Lagergren's first-order, pseudo-second-order, Elovich and Intraparticle equation were used to analyze kinetic data.

The Lagergren's first-order equation is written below.

$$\frac{dq_t}{dt} = k_L (q_e - q_t) \quad (3)$$

Where  $q_e$  is the amount of ammonium capture per mass of zeolites at equilibrium [mg/g],  $q_t$  (mg/g) is the amount of ammonium adsorbed per mass of zeolites at time  $t$  [min] and  $k_L$  [L/mg] refers to rate constant of Lagergren's equation. The Eq. 3 can be solved by simple separating variable with initial condition at  $t = 0$ ,  $q_t = 0$  and at  $t=t$ ,  $q_t = q_t$ . The solved equation may rewrite into a formula below.

$$q_t = q_e \frac{q_e}{k_L t + q_e} \quad (4)$$

The pseudo-second-order is stated as follows:

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \quad (5)$$

where  $k_2$  refers to rate constant of pseudo-second-order equation. The Eq. 6 can be solved by simple separating variable with initial condition at  $t = 0$ ,  $q_t = 0$  and at  $t=t$ ,  $q_t = q_t$ . The solved equation may rewrite into a formula as follows:

$$q_t = q_e \frac{q_e}{1 + (k_2 t) q_e} \quad (6)$$

The Elovich equation is written below in Eq. 7.

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \quad (7)$$

where  $\alpha$  and  $\beta$  are kinetic parameters of Elovich model. The Eq. 7 can be solved by simple separating variable with initial condition at  $t = 0$ ,  $q_t = 0$  and at  $t=t$ ,  $q_t = q_t$ . The solved equation may rewrite into a formula below.

$$q_t = \frac{1}{\beta} \ln(1 + \alpha \beta t) \quad (8)$$

The Intraparticle model is described in Eq. 9.

$$q_t = k_i t^{1/2} + C \quad (9)$$

where  $k_i$  is the intraparticle rate constant and  $C$  is the intercept.

### 2.4.2 Ion exchange ammonium isotherm study.

Isotherm was fitted using several models, i.e., Langmuir, Langmuir-Vageler, Freundlich and Temkin.

The Langmuir equation is as follows:

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L C_e} \quad (10)$$

where  $q_{max}$  is the monolayer maximum capacity [mg/g] and  $K_L$  is the equilibrium constant of Langmuir.

The Langmuir-Vagelar equation is presented below.

$$q_e = \frac{r q_{max}}{r + K_{LV} C_e} \quad (11)$$

where  $r = V C_0 / m$ ,  $V$  is ammonium solution volume (L),  $C_0$  is initial ammonium concentration solution (mg/L),  $K_{LV}$  is Langmuir-Vageler constant.

The Freundlich equation is stated below.

$$q_e = K_F C_e^{1/n} \quad (12)$$

where  $K_F$  is the Freundlich capacity factor.

The Temkin equation is as follows:

$$q_e = B \ln(K_T C_e) \quad (13)$$

where  $B$  is the heat of adsorption parameter and  $K_T$  is an equilibrium binding constant.

Non-linear least squared (NLLS) method was applied to fit the experimental data with models which generated more accurate results as compared to the linearization method [5, 10]. Error analysis was performed based on the error sum of squares (SSE).

$$SSE = \sum_{i=1}^n (q_e - q_{e,calc})^2 \quad (14)$$

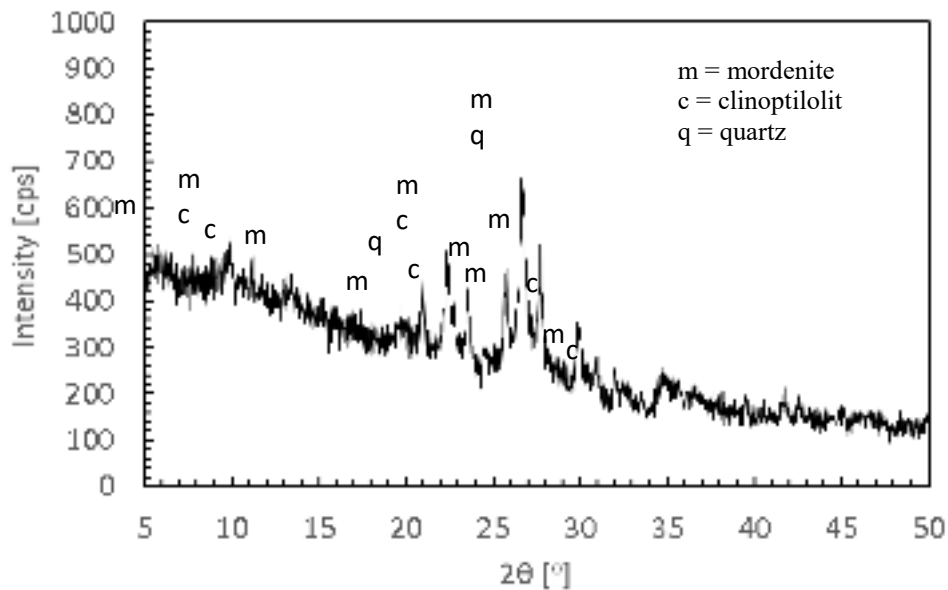
where  $q_{e,calc}$  is the amount of ammonium capture per mass of zeolites at equilibrium calculated by model [mg/g].

### 3. Results and Discussion

#### 3.1 Natural zeolites characterization

##### 3.1.1 X-ray diffraction.

Based on the XRD pattern in Fig. 1, Bayah natural zeolites are identified as mordenite (Card no: 49-0924), quartz (Card no: 46-1045) and clinoptilolite (Card no: 70-1859). Mostly, natural zeolites occurred in Java Island are mordenite and clinoptilolite dominant phase. For examples are natural mordenite from Pacitan East Java [11], natural clinoptilolite from Sukabumi [12]. The intensity of Bayah zeolites is lower as compared with synthetic and Klaten mordenite which suggested that the crystallinity is low [13]. Three highest peaks were detected at  $2\theta = 26.6^\circ, 22.4^\circ, 27.7^\circ$  with intensity 245, 120, and 108 counts, respectively.

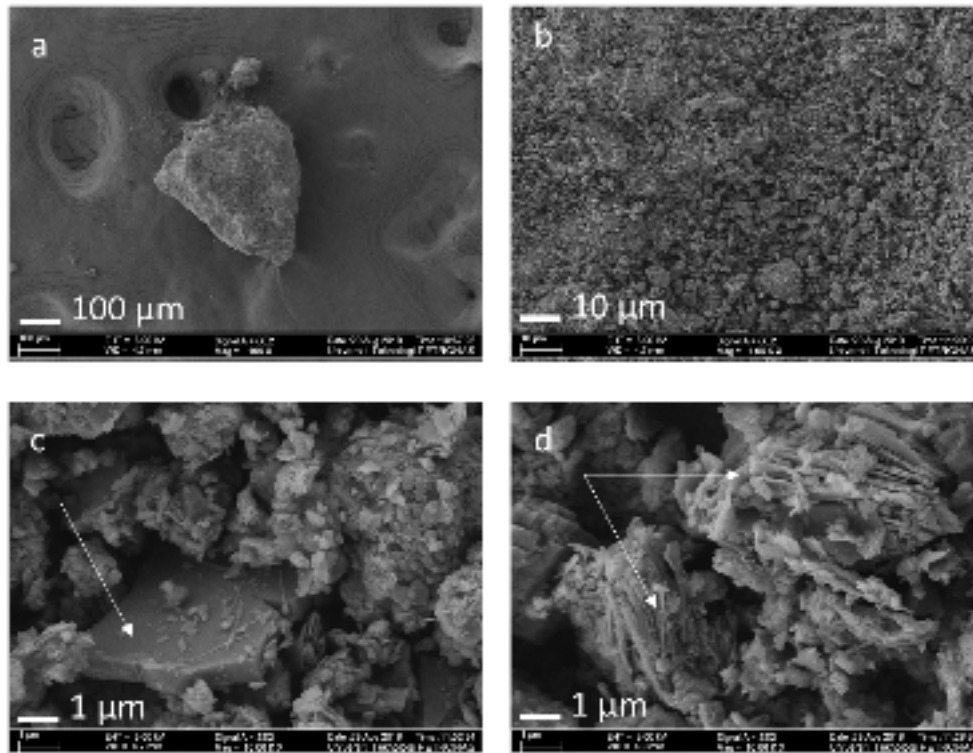


**Figure 1.** XRD patterns of the natural zeolites.

### 3.1.2 Scanning electron microscope-energy dispersive X-ray

Fig. 2a shows a single particle of natural zeolites with 0.39 mm in size, which consist of crystalline and non-crystalline materials. High magnification in Fig. 2b describes that the single particle was composed by smaller particles. Further magnification up to 10000 in Fig. 2c reveals the morphology of Bayah natural zeolites. The platy shape in Fig. 2c suggested the morphology of clinoptilolite. On the other hand, mordenite was found with needle morphology as seen in Fig. 2d.

Elemental analysis by SEM-EDX is presented in Table 1. The Si/Al ratio is 4.4 which is within the range of natural mordenite and clinoptilolite, i.e., Si/Al 4.0-6.0 [14, 15]. The Si/Al ratio of Bayah zeolites were typical of high aluminum content zeolite which is good for ion-exchange application as it provided more ion exchangeable sites. There is some element observed such as  $K^+$ ,  $Ca^{2+}$ ,  $Na^{2+}$  which most likely were the cations attached on the exchangeable sites. Although, some of those elements probably occurred in their oxide forms. Potassium is one of macronutrient which is needed by plants. Hershey et. al. [16] investigated the application of natural clinoptilolite to plant chrysanthemum. They found that 50 g clinoptilolite without adding extra potassium per 1.5 L of potting medium produced 3-month chrysanthemum leaves, stems and flowers equal to those obtained with a daily irrigation with 234 ppm of potassium. Hence, the as-received Bayah zeolites are potential materials for fertilizer because of its high potassium content.



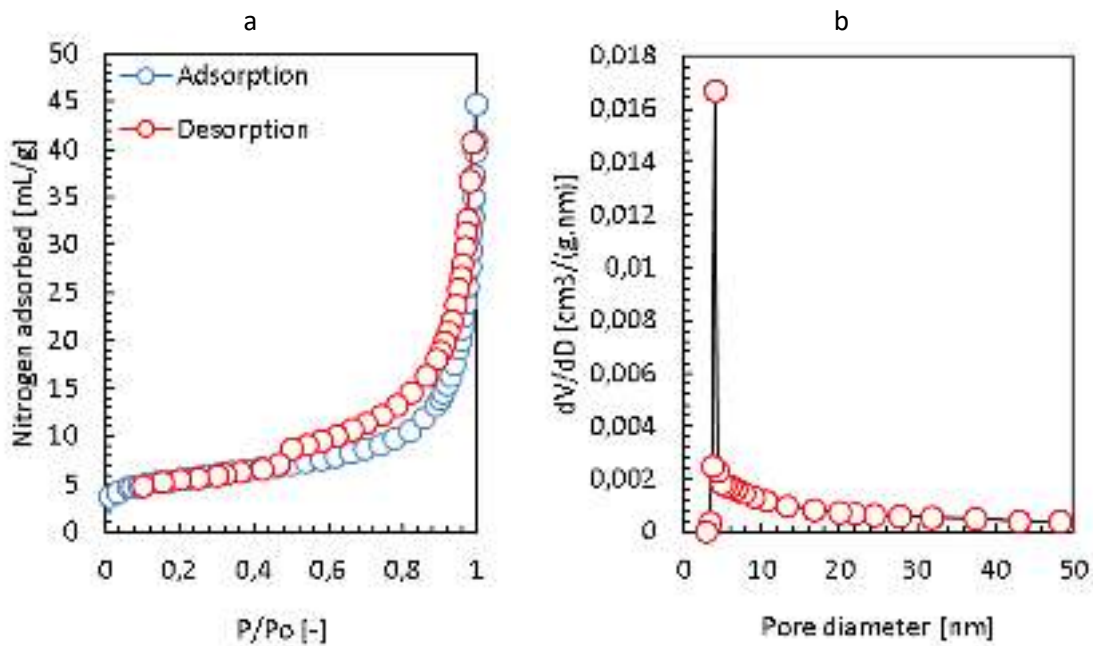
**Figure 2.** SEM images of the natural zeolites with different magnifications (a) 100x (b) 1000x (c) 10000x (d) 10000x on another spot.

**Table 1.** Elemental composition Bayah natural zeolites.

Elements	% wt.
C	8.475
O	53.595
Na	0.4
Mg	0.59
Al	5.845
Si	26.65
K	2.685
Ca	1.28
Fe	0.485

### 3.1.3 Nitrogen adsorption-desorption.

The nitrogen isotherm of Bayah natural zeolites in Fig. 3a is a typical of type IV according to IUPAC classification [17]. The hysteresis as pointed by the arrow in Fig. 3a suggested that the mesopore volume is high. The natural zeolites from Klaten shows the hysteresis as well [18]. The mesopore volume is not only contributed by the pore inside the crystals but most likely because of the void between crystals and debris in the natural zeolites particles as seen in Fig. 3b, c and d. This type of void was also found when studied nanoparticle in which the voids formed because of stacking the particles [19]. BJH desorption pore size distribution is presented in Fig. 3b. The mesopore size most likely within size of 3-5 nm as suggested by the BJH model.



**Figure 3.**(a) Nitrogen adsorption-desorption isotherm of Bayah natural zeolites (b) BJH desorption pore size distribution.

The textural properties based on nitrogen physisorption is presented in Table 2. Single point and BET method show almost similar number of total surface area 18.5 and 18.8 m<sup>2</sup>/g, subsequently. However, Langmuir model provided a higher number of total surface area ca. 28 m<sup>2</sup>/g. The assumption of single layer on the Langmuir equation overestimated the total surface area as compared to the BET with multilayers model.

**Table 2.** Textural Properties of Bayah natural zeolites.

Textural properties	Surface area [m <sup>2</sup> /g]
BET	19
Langmuir surface area	28
t-plot micropore area	5.9
t-plot external surface area	12.9
	Pore volume [cm <sup>3</sup> /g]
Total pore volume	0.060
t-plot micropore volume	0.003
Mesopore volume	0.057

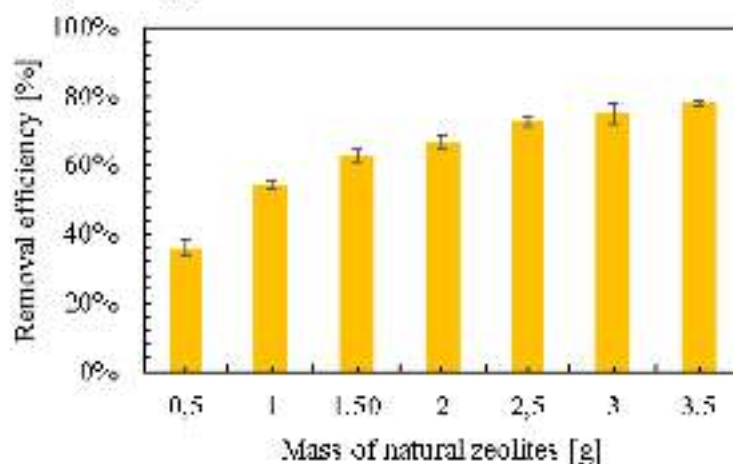
Comparison of Bayah zeolites textural properties with other zeolites is presented in Table 3. Total BET surface area of Bayah zeolites is smaller as compared to the other zeolites. Accordingly, total pore volume of Bayah zeolites is lower. However, the micropores volume which created by framework of mordenite and clinoptilolite is comparable with other natural zeolites. The high micropore volume showed by Klaten and Demirci zeolites, which indicate a high content of zeolites. The Si/Al ratio of Bayah natural zeolites is similar with other Indonesian natural zeolites except Klaten zeolites which showed a higher Si/Al ratio. For ion exchange application, the low Si/Al ratio favored the adsorption rate.

**Table 3.** Comparison of textural properties and Si/Al ratio of Bayah with the other natural zeolites.

Origin of natural zeolites	Zeolites type	BET surface area [m <sup>2</sup> /g]	pore volume (m <sup>3</sup> /g)	micropore volume [cm <sup>3</sup> /g]	Si/Al	Ref.
Bayah, Indonesia	Mordenite, clinoptilolite	19	0.060	0.003	4.6	This research
Sukabumi, Indonesia	Clinoptilolite, mordenite	31	0.089	nd	4.6	[12]
Ponorogo, Indonesia	Mordenite	30	0.116	0.002	4.5	[3]
Klaten, Indonesia	Mordenite, clinoptilolite	133	0.099	0.055	6.0	[20]
Kucin, Slovakia	Clinoptilolite	33	0.135	0.003	4.1	[21]
Demirci, Turkey	Clinoptilolite	112	0.330	0.045	4.7	[22]

### 3.2 The effect of mass loading

The mass loading greatly affected the percentage of ammonium removal as presented in Fig. 4. The experiment was performed triplicate to obtain the error bar which shows a relatively small deviation from 0.67 to 2.25. The ammonium removal efficiency was increase as the zeolites mass increase. The increasing of removal efficiency was larger from 36% to 63% when zeolite mass increase from 0.5 g to 1.5 g. After that, the increasing of removal efficiency was lower. Millar et.al. [5] explained that the driving force of ion-exchange process is the ratio of ammonium concentration to the mass of zeolites. To be precise, the driving force of ion-exchange process was the ratio of acid sites number provided by the zeolites to the number of ammonium in the solution. Accordingly, Widiastuti et.al. [4] showed that a high initial ammonium concentration resulted in a high removal efficiency because of a high driving force.

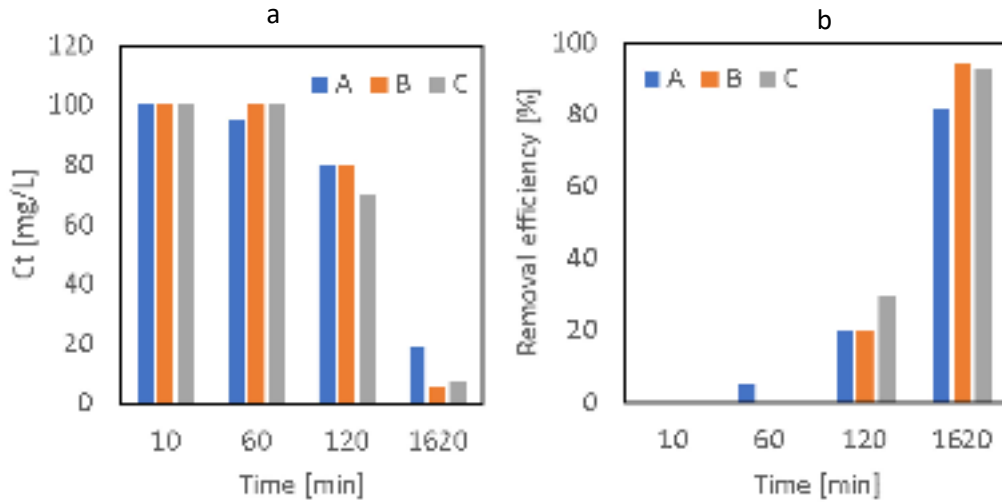
**Figure 4.** The effect of natural zeolites loading on removal efficiency.

### 3.3 The effect of particle size

Particle size of Bayah zeolites is not significantly affected the ammonium adsorbed as seen in Fig. 5a, b. In contrast, Erdogan and Ulku concluded that the smaller particle of Gordes zeolite lead to a high mass transfer rate because the large external surface area [23]. The contradiction result is most likely because the Bayah natural zeolites are mainly consisted of mesopores as compared to the



microporous. The ratio of mesopores to micropores volume was 19. Hence, the external mass transfer is not limiting rate on the ammonium exchange. This is also an indication that the ammonium exchange occurred dominantly on the external surface instead of the micropore area.



**Figure 5.** The effect of particles size on ammonium adsorption: sample A (size 0.84-2.0 mm), sample B (6.3-9.5 mm), sample C (12.7-16 mm) (a) ammonium concentration in solution (b) % removal efficiency.

### 3.4 Kinetic study of ammonium exchange

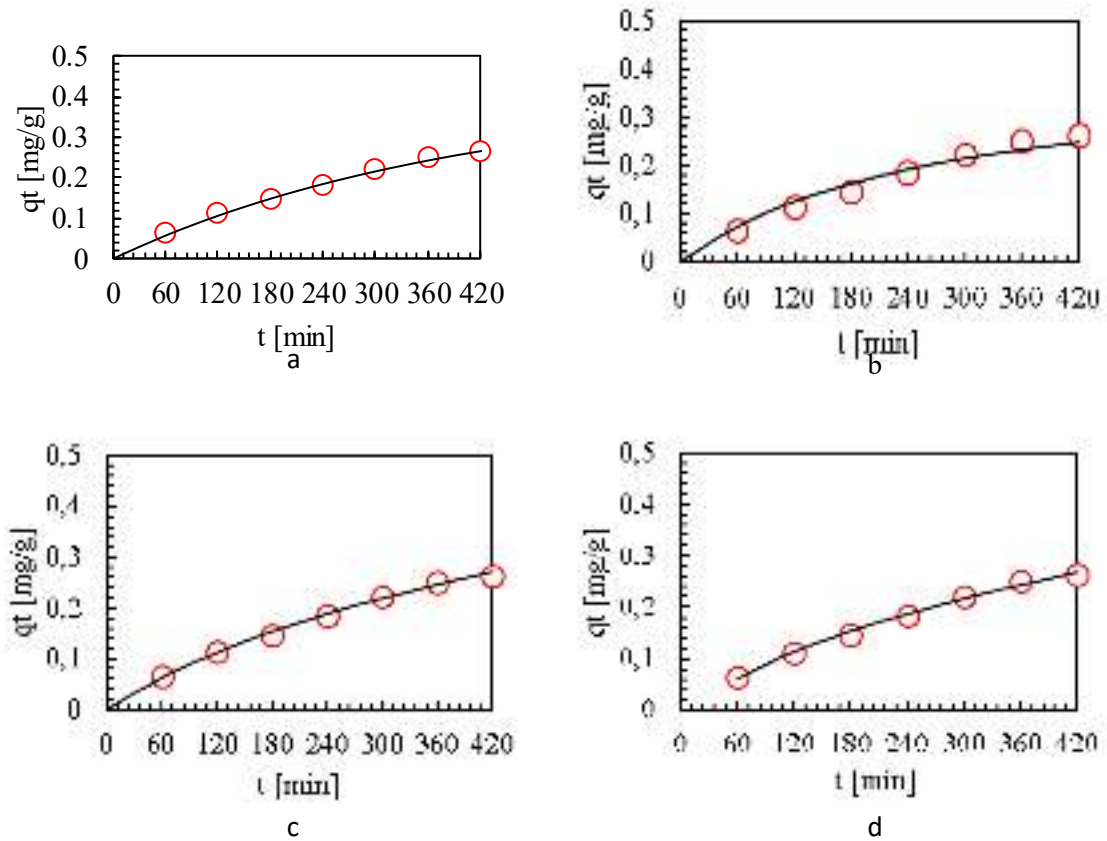
Kinetic study was performed to describe the speed of mass transfer from the bulk solution onto the zeolites which is important for unit operation design aspect. The experimental data and four kinetic models were fitted using NLLS method presented in Fig. 6. We can say all models were fitted with the experimental data with some error. The most fitted model based on criteria of SSE was the Elovich equation with error  $1.6 \times 10^{-4}$  as seen in Table 4. In the second and third place were intraparticle diffusion and Lagergren's first order, subsequently. The equilibrium was measured at 0.41 mg/g after 72 h.

The Elovich model was satisfied for chemical adsorption of reactive dye on chitosan which was in agreement with the original development of The Elovich for chemical adsorption process [24]. The fact that the Elovich model was the best fitted indicated that the adsorption of ammonium on zeolites Bayah is typical of chemical adsorption. Hence, the number of exchangeable cation sites on the zeolite would be the critical factor affected the ammonium loading.

The intraparticle model is presented in Fig. 6d. The curve showed that the line is in one region only which showed that the process is not controlled by both of interparticle and the intraparticle mass transfer. Typically, if the process controlled by intraparticle mass transport, the curve indicated by a high gradient of the first line followed by a less gradient of the second line as observed by Widiastuti et.al. [4]. Hence, it is most likely that the process of ammonium capture on the Bayah zeolites is controlled by chemical process.

**Table 4.** Kinetic parameters of various model for ammonium capture.

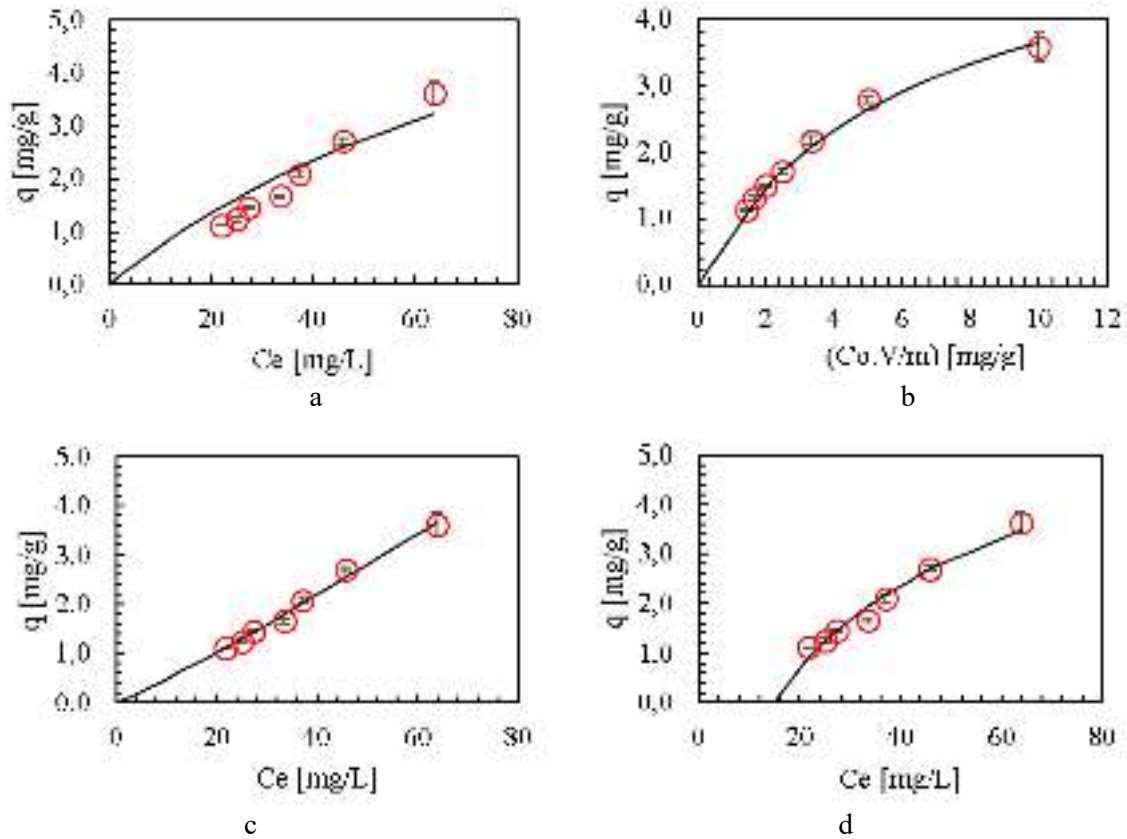
Kinetic models	Parameters		Error
Lagergren's 1 <sup>st</sup> order	$k_L$ [ $h^{-1}$ ]	$q_e$ (mg/g)	SSE [ $mg^2/g^2$ ]
	0.0025	0.41	0.00019
Pseudo 2 <sup>nd</sup> order	$k_s$ [ $g\ mg^{-1}\ h^{-1}$ ]	$q_e$	SSE [ $mg^2/g^2$ ]
	-0.0089	0.41	0.00113
Elovich	$\alpha$	$\beta$	SSE [ $mg^2/g^2$ ]
	0.0012	4.1954	0.00016
Intraparticle diffusion	$k_i$	C	SSE [ $mg^2/g^2$ ]
	0.0162	-0.0641	0.00017



**Figure 6.** Non-linear least square fitted kinetic model of (a) Lagergren's first order, (b) Pseudo-second order, (c) Elovich and (d) intraparticle diffusion.

### 3.5 Ammonium exchange isotherm

The experimental data fitted to various isotherm models are presented in Fig. 7. The Langmuir model was developed based on several assumptions such as monolayer adsorption, homogeneous surface, and no interaction between adsorbed molecules [25]. It is clearly seen from Fig. 7 that the Langmuir model failed to fit the data. The Langmuir-Vageler model showed the lowest error among other models (Table 3). This is in agreement with another study which also found the Langmuir-Vageler best fitted instead of the Langmuir model [5]. The Langmuir-Vageler model was successful to fit the experimental data because it correlates the driving force with the mass of zeolites which is important factor of ammonium uptake[4, 5]. Maximum ammonium loading to achieve monolayer coverage of Bayah zeolites predicted by Langmuir model was 8.88 mg/g. The number was larger than the maximum ammonium loading predicted by Langmuir-Vageler model with 5.84 mg/g.



**Figure 7.** Non-linear least square fitted model of (a) Langmuir, (b) Langmuir-Vageler, (c) Freundlich and (d) Temkin.

The Freundlich equation was the second-best fit to the experimental data. The model parameters and SSE were presented in Table 5. According to Freundlich model, the adsorption of ammonium into natural zeolites is controlled by the chemical process which is indicated by  $n < 1$ . The main process of ion exchange is described in Eq. 16 and 17. It is most likely that the chemical process controls the rate because of the Bayah zeolites having a high mesopore and large external surface area. As a result, the mass transport process is much faster as compared to the chemical ion exchange rate. This is in agreement with another investigation which showed that the chemical process controlled the rate instead of the mass transport because of the large pore size and high surface area [26].

Ion exchange process for monovalent ion like  $K^+$ ,  $Na^+$ , etc.



Where M is the metal ion. Ion exchange process for divalent ion  $Ca^{2+}$ ,  $Mg^{2+}$ , etc.



**Table 5.** Parameters of various fitted isotherm models for ammonium capture.

Isotherm models	Parameters	Error	
Langmuir	qmax [mg/g]	$K_L$ [L/mg]	SSE [mg <sup>2</sup> /g <sup>2</sup> ]
	8.88	0.009	0.56
Langmuir-Vageler	qmax [mg/g]	$K_{LV}$ [mg/g]	SSE [mg <sup>2</sup> /g <sup>2</sup> ]
	5.84	6.03	0.04
Freundlich	$K_F [L^{1.1}/(g \cdot mg^{0.1})]$	n [-]	SSE [mg <sup>2</sup> /g <sup>2</sup> ]
	0.0381	0.9097	0.09
Tempkin	B [mg/g]	$K_T$ [L/mg]	SSE [mg <sup>2</sup> /g <sup>2</sup> ]
	2.385	0.0675	0.12

### 3.6 Potential application of Bayah Zeolites for Agriculture

The properties of Bayah natural zeolites revealed promising results for application in agriculture. According to EDX analysis, the Bayah natural zeolites are rich in potassium which is needed for the plants as the macronutrient. The zeolite framework of mordenite and clinoptilolite are suitable for ion-exchange purpose. The large pore zeolites such as faujasite (FAU) and beta (BEA) framework were successfully applied for adsorption of pesticide to prevent ground water contamination [27]. The Bayah natural zeolites major phase was mordenite (MOR) which is a large pore zeolite. Hence, the investigation of natural zeolite for adsorption of pesticide should be performed to discover other beneficial of the Bayah natural zeolites.

Despite its high phase impurities, Bayah natural zeolites are potentially applied for ammonium removal and followed by the utilization as fertilizer. The most ideal scheme probably to use natural zeolites for ammonium removal in wastewater treatment and anaerobic digester. Then, after capturing ammonium, the NH<sub>4</sub><sup>+</sup>-natural zeolites are ready to use as a fertilizer. Hence, the benefits of natural zeolites would be for ammonium removal in waste and slow releasing the ammonium for plants need. In case of nitrogen content in the natural zeolite was not enough for plants, the mixing scenario of natural zeolites with synthetic fertilizer could also possible to be applied as reported by Bernardi et.al. for Brazilian zeolites [28]. The natural zeolites not only supply nutrient to plants but also store water. Hence, it is potential to be used in semi-arid area [7].

The price of Bayah natural zeolites in the commercial store was 0.14 USD per kg. The natural zeolites were mostly sale for cat litter purpose. The price of urea fertilizer 46% was 0.34 USD per kg. Hence, if the NH<sub>4</sub><sup>+</sup> natural zeolites mixed with urea, then the cost of fertilizing would decrease significantly. Another advantage is that no need for regeneration of zeolites in the ammonium adsorption unit operation. One more thing is that the ammonium inside the zeolites pore will be released slowly. As the result, the ammonium that release into the environment will not increase sharply within a short time and the utilization of ammonium by the plants will be more efficient. The eutrophication of river and lake body would also be avoided.

## 4 Conclusions

In summary, we have successfully characterized the Bayah natural zeolites. Mordenite and clinoptilolite were the main zeolitic phases with K<sup>+</sup> and Ca<sup>2+</sup> as the major constituent of cations. Beside the zeolitic phase, the Bayah natural zeolites show high intensity of quartz as a non-zeolitic phase. The micropore volume was small as compare to other natural zeolites throughout the world. Accordingly, the Bayah natural zeolites ammonium loading was smaller as compared to the other natural zeolites. The ammonium adsorption was controlled by the chemical process instead of the physical external and internal pore transport. Furthermore, we have studied isotherm and kinetic of ammonium exchange using various models. The Langmuir-Vageler isotherm model was best fit

using non-linear least square methods. The Elovich kinetic model showed the lowest error with experimental data. The Bayah natural zeolites could be potential for ammonium capture and followed by application for slow release fertilizer.

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