



Recovering ammonium from real treated wastewater by zeolite packed columns: The effect of flow rate and particle diameter

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ABSTRACT

Nitrogen (N) recovery from wastewater is a desirable way to create a (N) neutral society in view of a circular economy approach. Nitrogen recovery from wastewater by employing adsorption columns filled with zeolite can be a very attractive solution. This study assessed the effect of influent flow rates (namely, 1.6 and 2.3 L h⁻¹) and particle diameters (namely, 0.5–1.0 and 2.0–5.0 mm) of zeolite packed in columns on recovering NH₄⁺ from real domestic treated wastewater (RDTWW). Findings revealed that maximum NH₄⁺ recovery can be achieved by using zeolite with the smallest particle diameter (0.5–1.0 mm) and the highest influent flow rate (2.3 L h⁻¹). The maximum NH₄⁺ adsorption rate was 1.2, 21 and 9.8 mg NH₄⁺ kg⁻¹ h⁻¹ after 205, 32 and 35 h of operation. NH₄⁺ adsorption data were analysed by fitting them to both pseudo-first and pseudo-second order kinetic models. The former model best approximated NH₄⁺ adsorption data. Such a result suggested that the amount of NH₄⁺ adsorbed depended solely on the amount of NH₄⁺ in contact with the zeolite surface. Results successfully established the application of zeolite-packed columns in removing NH₄⁺ from real domestic treated wastewater and the effects of process parameters.

1. Introduction

Recovering N from treated wastewater is crucial to providing clean water for the world population (Naddaf, 2023), avoiding eutrophication of the aquatic environment (Preisner, 2023) and having an alternative and sustainable source of N within a circular economy perspective (Guaya et al., 2018; Mannina et al., 2021; Muscarella et al., 2023a).

Treated wastewater holds from 0.9 to 30 mg L⁻¹ of NH₄⁺, depending on the type of treatment process used and on the characteristics of the influent (Guaya et al., 2016; Guida et al., 2020–2021; Pinelli et al., 2022).

Physical (e.g., air stripping, ion exchange and adsorption, reverse osmosis) chemical (e.g., chemical precipitation, electrochemical oxidation), and biological (e.g., nitrification and denitrification, anaerobic ammonium oxidation, partial nitrification) techniques can recover N from treated wastewater (Dong et al., 2019; de Magalhães et al., 2022). Prominent among these are the ion exchange and adsorption processes, using low-cost industrial adsorbents that are environmentally sustainable and recyclable (López-Rosales et al., 2022), such as zeolite, clay, polymeric ion exchangers (Huang et al., 2010; Fu et al., 2020; Muscarella et al., 2023a). Zeolites are highly porous aluminosilicate minerals with high cation adsorption capacity due to the isomorphous substitution of silicon ion (Si⁴⁺) with aluminium ion (Al³⁺), resulting in a net negative charge. The negative charges are counterbalanced by cations such as sodium

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(Na⁺), potassium (K⁺), calcium (Ca²⁺) and magnesium (Mg²⁺), which can be exchanged by NH₄⁺ (Sengupta et al., 2015; Han et al., 2019; Muscarella et al., 2021). Therefore, NH₄⁺ enriched zeolites can be applied in agriculture to improve soil physical and chemical properties and as slow-release fertilizers within a circular economy perspective (Sengupta et al., 2015; Mannina et al., 2022; Muscarella et al., 2023a).

The ability of zeolites in the removal of NH₄⁺ from aqueous solution is influenced by several factors, including the homoionic forms of the zeolites (Muscarella et al., 2021), their particle diameter (Huang et al., 2010), pH (Li et al., 2020), influent NH₄⁺ concentration (Li et al., 2020), retention time (Sprynskyy et al., 2005; Tran et al., 2020), ionic competition with other cations (Huang et al., 2010; Vociante et al., 2018), zeolite mineralogical composition (Muscarella et al., 2023b) and temperature of the solution (Fu et al., 2020).

Huang et al. (2010) studied in batch test the effects of NH₄⁺ ion removal from NH₄⁺-enriched solutions (80 mg NH₄⁺ L⁻¹) using natural zeolite particles with a diameter ranging from 0.074 to 0.3 mm and contact time ranging from 10 to 300 min. They found high NH₄⁺ ion removal efficiency by decreasing particle size and increasing contact time.

On the other hand, Sprynskyy et al. (2005) investigated the NH₄⁺ adsorption capacity of zeolite (clinoptilolite) on a pilot column scale under dynamic conditions using particle diameters ranging from 1.4 to 2.0 to 0.125–0.35, flow rates of 0.11, 0.36, and 0.54 L h⁻¹ and NH₄⁺ enriched solution with a concentration of 100 mg L⁻¹. Overall, their results suggested that the maximum NH₄⁺ adsorption capacity of zeolite occurs by decreasing particle size and increasing flow rate. Such results are reasonable because decreasing the particle size increases the specific surface area for NH₄⁺ adsorption, whereas increasing the flow rate increases the amount of NH₄⁺ through the column and thus in contact with the adsorbent.

However, to scale up from batch scale to real scale, pilot studies using real treated wastewater are needed to find out the most appropriate flow rate and zeolite particle size diameter to maximize NH₄⁺ removal from wastewater and its adsorption by zeolite.

Moreover, to find out the mechanisms by which NH₄⁺ is adsorbed by zeolite, adsorption kinetics must be investigated. Indeed, by fitting experimental data to kinetic models, the nature of the interaction (physical-chemical or chemical) between zeolite and NH₄⁺ (Revellame et al., 2020) and the adsorption mechanisms (mainly ion exchange and adsorption) (Jørgensen, 1989) can be revealed. Recently, Muscarella et al. (2023b) fitting experimental data of NH₄⁺ adsorption on natural zeolites with different mineralogical mixtures, found out that the NH₄⁺ sorption occurs by two simultaneous pseudo-first-order reactions: adsorption process and ion exchange. In the light of above, this study aimed to investigate, at a pilot scale, the effect of zeolite particle diameter and flow rate of real domestic treated wastewater (RDTWW) in adsorbing NH₄⁺. The mass balance approach can reveal the NH₄⁺ adsorption efficiency of the zeolite packed in the column. This study further aimed to investigate the adsorption kinetics of the most efficient zeolite in adsorbing NH₄⁺ by fitting experimental data to pseudo-first- and second-order models.

2. Materials and methods

2.1. Zeolites used for NH₄⁺ recovery from column pilot scale plant

Zeolite used in the pilot scale plant was made up of 85% of clinoptilolite, 8% of cristobalite, 4% of illite, and 3% plagioclase. Clinoptilolite is a member of the heulandite group (HEU) and has the chemical formula (Na,K)₆Al₆Si₃₀O₇₂·20H₂O (Muscarella et al., 2021). It has a tetrahedral structure made up of units of SiO₄⁴⁻ and AlO₄⁵⁻. It has a bulk density of 0.98 g cm⁻³, a surface area of 40 m² g⁻¹, and a pH of 7.6. The Si/Al ratio is 4.8–5.5. The two most abundant exchangeable cations, counterbalancing the negative charges formed following the isomorphic substitution of Si⁴⁺ with Al³⁺, were K⁺ and Ca²⁺. Before its use, clinoptilolite was sieved to obtain particles with a 2.5–5.0 and 0.5–1.0 mm diameter, washed three times with distilled water, and dried at 105 °C.

2.2. NH₄⁺ recovery column pilot scale plant and tested variables

A pilot-scale column plant filled with zeolite was constructed at the Water Resource Recovery Facility (WRRF) of Palermo University Campus (Mannina et al., 2021a). The pilot plant specifically consisted of three polymethylmethacrylate columns, each with a height of 15 cm, an internal diameter of 5 cm, and a total volume of 0.29 L (Fig. 1). Each column was filled with 288 g of natural zeolite.

Zeolite was packed between two layers of cleaned quartz sand (ø 2.0–5.0 mm) to immobilize it and enable a uniform distribution of the flow over the cross-sectional region. A biological pilot plant that treated real domestic wastewater and equipped with an ultra-filtration membrane to eliminate harmful bacteria supplied the columns with RDTWW (Mannina et al., 2022; Cosenza et al., 2022). The RDTWW was pumped into the columns in upward flow mode using a peristaltic pump (Watson Marlow-Qdos 30 Universal). Characteristics of the RDTWW used to feed natural zeolite-packed columns are reported in Table 1.

Three setups were tested to evaluate the effect of flow rate and particle diameter on the amount and rate of NH₄⁺ removal by zeolite-packed columns: setup I, setup II and setup III. The setup I lasted 588.5 h, during which the flow rate through the columns packed with zeolite having a particle diameter of 2.5–5.0 mm was maintained at 2.3 L h⁻¹ per column. Setup II lasted 130.5 h; the flow rate was maintained at 2.3 L h⁻¹ per column, but the zeolite particle diameter was 0.5–1.0 mm. Setup III lasted 249.5 h, the flow rate was set at 1.6 L h⁻¹, and zeolite with a particle diameter of 0.5–1.0 mm was used. Before starting each test, the required amount of RDTWW was accumulated in a 500 L tank to ensure a constant flow with a fixed NH₄⁺ concentration.

For each test, the amount and rate of NH₄⁺ adsorbed by zeolite-packed columns during the test were assessed by monitoring the NH₄⁺ mass of the inlet and the outlet flow from the columns. The mass of NH₄⁺ was calculated by multiplying the concentration of NH₄⁺ of the inlet and the outlet flow from the columns per column crossing time. Reported data are the average values of the three columns.



Fig. 1. Zeolite-packed columns. Each column had a height of 15 cm, an internal diameter of 5 cm, and a total volume of 0.29 L.

Table 1

Characteristics of RDTWW used to feed natural zeolite-packed columns for NH_4^+ removal.

Parameter	Symbol	Units	Average \pm SD
Soluble COD	sCOD	mg L^{-1}	43 ± 26
Ammonium	NH_4^+	mg L^{-1}	$3\text{-}21 \pm 5$
Phosphate	$\text{PO}_4\text{-P}$	mg L^{-1}	10 ± 2
Flow Rate	Q_{IN}	L h^{-1}	1.6–2.3
<i>Escherichia Coli</i>	EC	$\text{MPN } 100 \text{ mL}^{-1}$	2.8–6.2
Empty bed contact time	EBCT	min	10.6–7.6
Reaction	pH	–	8.0 ± 0.2

2.3. Analytical methods

RDTWW samples collected before and after passing through the column were filtered using membrane syringe filters with a pore size of $0.45 \mu\text{m}$ before being analysed by ion chromatography to remove contaminants and safeguard the analytical columns (Michalski, 2018). The concentration of NH_4^+ , as well as of Ca^{2+} , Mg^{2+} , K^+ , and Na^+ , were determined by the ionic chromatograph Dionex Easion (Thermo Scientific, Milan, Italy) equipped with a Dionex IonPac CS12A (4 x 250 mm) column. The chemicals utilised were Thermo Scientific's Dionex Cation regenerant solution, Thermo Scientific TBAOH (100 mM), Dionex CS12A Eluent Concentrate, and Thermo Scientific Methanesulfonic Acid (20 mM).

2.4. Adsorption kinetics

The kinetics of NH_4^+ adsorption was evaluated by modelling experimental data from zeolite packed column. Data were analysed by applying both pseudo-first and pseudo-second-order models. The pseudo-first order model (eq. (1)) (Lagergren, 1898) assumes that the adsorption rate is solely dependent on the amount of NH_4^+ in contact with the zeolite:

$$q_t = q_e (1 - e^{-k_1 t}) \quad (1)$$

where q_t in $\text{mg NH}_4^+ \text{ L}^{-1}$ is the amount of NH_4^+ adsorbed by zeolite at time t , q_e is the equilibrium adsorption capacity ($\text{mg NH}_4^+ \text{ L}^{-1}$) and k_1 is the pseudo-first order monomodal constant. The latter is directly related to the adsorption rate of NH_4^+ by zeolite. The higher is the k_1 value, the faster is NH_4^+ adsorption rate.

The pseudo-second order model is described by eq. (2) (Ho et al., 1996):

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

where q_t ($\text{mg NH}_4^+ \text{ L}^{-1}$) is the amount of NH_4^+ adsorbed at time t , q_e is the amount of NH_4^+ adsorbed at equilibrium and ($\text{mg NH}_4^+ \text{ L}^{-1}$) is the pseudo second-order rate constant and is constant related to the energy of adsorption.

The pseudo-second order model assumes a chemisorption process, i.e. an adsorption process that involves a chemical reaction and that implies the formation of a covalent bond between the molecule and one or more atoms on the surface. In this scenario, the rate of adsorption depends on the adsorption capacity rather than the concentration of NH_4^+ in contact with the zeolite (Sahoo and Prelot, 2020). The performance of the different kinetic models was evaluated through the application of different statistical parameters, such as correlation coefficient (R^2), chi-square (χ^2), residual sum of squares error (SSE), and mean sum of squares error (MSE).

The kinetics have been analysed using a user-friendly UI developed based on Excel (Wang and Guo, 2020) and Oring (Version 7.5) software program.

3. Results and discussion

3.1. NH_4^+ adsorption from RDTWW

The total amount of NH_4^+ adsorbed by zeolite as a function of particle diameter and RDTWW flow rate was determined by monitoring the NH_4^+ concentration in the inlet and outlet flow from the columns. Zeolite adsorbed 11%, 49%, and 27% of NH_4^+ passed through the columns with setup I, II, and III, respectively (Fig. 2).

Setup I and setup II enabled the assessment of the role of zeolite particle size in the NH_4^+ adsorption; indeed, while the flow rate was maintained constant, the zeolite particle diameter was greater in setup I to setup II. It was found that the total amount of NH_4^+ adsorbed with setup I (Fig. 3) was doubled by that adsorbed by columns with setup II (Fig. 4) even in less time of operation, thus suggesting that decreasing zeolite particle diameter increases the total amount of NH_4^+ adsorbed. Such a result is reasonable because, depending on the adsorption process on the specific surface area, the lower the zeolite particle size, the higher the zeolite surface area available for NH_4^+ adsorption.

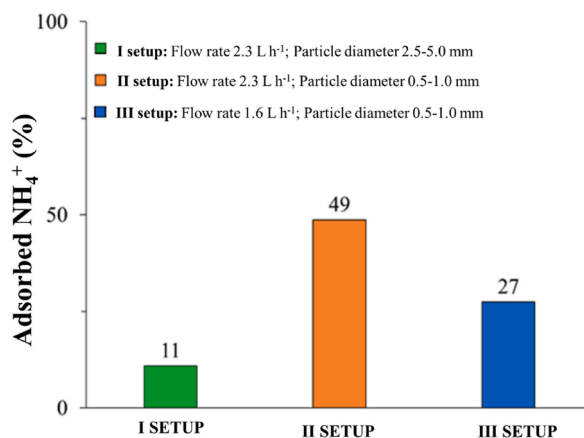


Fig. 2. Percentage of ammonium (NH_4^+) adsorbed by zeolite packed columns with three different setups.

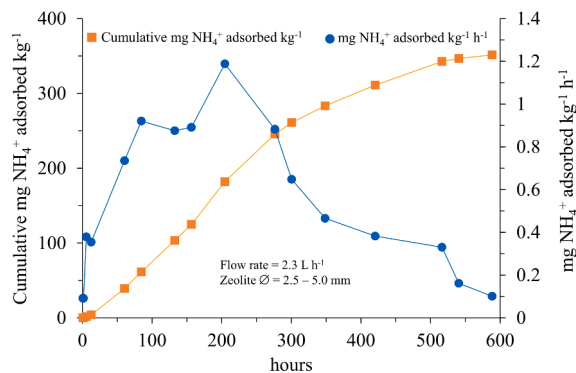


Fig. 3. Cumulative and hourly ammonium (NH_4^+) adsorbed per kg of zeolite with setup I.

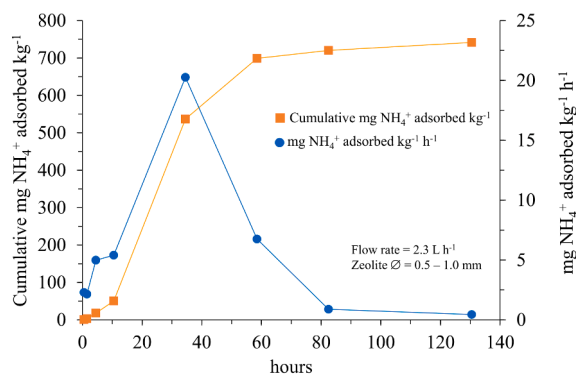


Fig. 4. Cumulative and hourly ammonium (NH_4^+) adsorbed per kg of zeolite with setup II.

Such findings agreed with those of [de Magalhães et al. \(2022\)](#), who investigated the effect of zeolite particle diameter on NH_4^+ adsorption, found the highest amount of NH_4^+ adsorbed by zeolite with the smallest particle diameter.

Besides the zeolite particle diameter, flow rate also played a key role in affecting the amount of NH_4^+ adsorbed by zeolite. Indeed, comparing setup II and III ([Fig. 5](#)), the greatest amount of NH_4^+ adsorbed occurred with setup III, which was characterized by a flow rate lower than that of setup II. However, more time was needed for columns with setup III compared to columns with setup II to adsorb the maximum amount of NH_4^+ . Moreover, the percentage of NH_4^+ adsorbed by columns with setup III was lesser than that adsorbed by columns with setup II ([Fig. 2](#)). Such behaviour can be ascribed to the low amount of NH_4^+ passed through the column with setup III due to the low flow rate (see [Fig. 5](#)).

Such findings agreed with those of [Sprynskyy et al. \(2005\)](#) who investigated NH_4^+ adsorption capacity of zeolite (clinoptilolite) on a pilot column scale under dynamic conditions using particle diameters ranging from 1.4 to 2.0 to 0.125–0.35, flow rates of 0.11, 0.36, and 0.54 L h^{-1} and NH_4^+ enriched solution with a concentration of 100 mg L^{-1} . They found that the maximum amount of NH_4^+ adsorption capacity occurs by decreasing particle size and increasing the flow rate, thus indicating that both factors play a crucial role in the adsorption process. Based on these results someone could argue that using zeolites with an even smaller diameter would be appropriate. However, this is not to be done because using particles smaller than 0.35 mm allows the formation of preferential channels or voids within the column reducing NH_4^+ adsorption ([Sprynskyy et al., 2005](#)).

3.2. Effect of zeolite particle diameter in adsorbing NH_4^+ from RDTWW

[Figs. 3 and 4](#) show the cumulative NH_4^+ adsorbed and the hourly adsorption rate per kg of zeolite under setup I and II.

As discussed above, in setup I and II, the flowrate fed to each column was maintained constant, equal to 2.3 L h^{-1} , while the zeolite particle size was decreased from 2.5 – 5.0 mm to 0.5–1.0 mm to assess its role (and consequently the role of specific surface) in the NH_4^+ adsorption process.

As noticeable from data reported in [Figs. 3 and 4](#), the significant effect of zeolite size in the adsorption process is worth noting. Indeed, while in setup I, the cumulated NH_4^+ adsorbed reached a value close to 350 mg NH_4^+ adsorbed kg^{-1} zeolite after 600 h of flushing ([Fig. 3](#)), in setup II, the cumulated NH_4^+ adsorbed almost doubled, reaching a steady state value close to 350 mg NH_4^+ adsorbed kg^{-1} zeolite after only 130 h of flushing ([Fig. 4](#)). In addition, the hourly (NH_4^+) adsorbed showed significant differences in the two investigated setups. Indeed, in setup I, the hourly adsorbed (NH_4^+) showed an increasing trend in the first 200 h of flushing, reaching a maximum value close to 1.2 mg NH_4^+ adsorbed kg^{-1} zeolite h^{-1} . In contrast, under setup II, the hourly adsorbed (NH_4^+) showed an increasing trend in the first 40 h of flushing, with a maximum value higher than 20 mg NH_4^+ adsorbed kg^{-1} zeolite h^{-1} , thus highlighting a

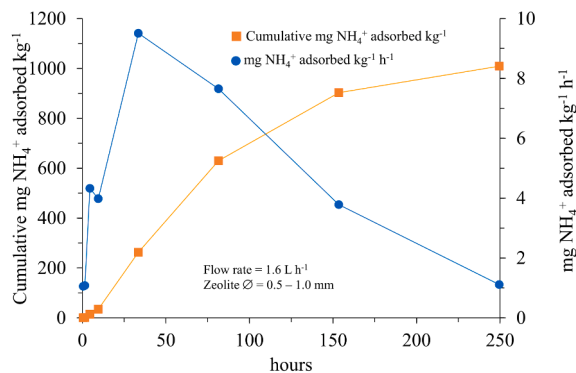


Fig. 5. Cumulative and hourly ammonium (NH_4^+) adsorbed per kg of zeolite with setup III.

much higher adsorption rate likely related to the significant increase of zeolite specific surface under setup II. As discussed above, since NH_4^+ adsorption occurs on the surface of the adsorbent material, the reduced particle size of the zeolite will increase the efficiency of the adsorption process. This result is in line with the observations of Pinelli et al. (2022), who found that Chabazite/Phillipsite, characterized by lower diameter compared to other investigated sorbent materials, had a high capacity to recover NH_4^+ from Municipal Wastewater (MWW).

From an operational point of view, the suggestion is twofold: if the aim is the NH_4^+ removal from wastewater, it would be better to operate with a zeolite characterized by higher particle size; in contrast, if the aim is to maximize NH_4^+ recovery, it would be better to use a zeolite with a lower particle size (higher specific surface).

3.3. Effect of flow rate in adsorbing NH_4^+ from RTDWW

Fig. 5 shows the cumulative NH_4^+ adsorbed and the hourly adsorption rate per kg of zeolite in setup III.

As previously mentioned, in setup III, the zeolite particle size was maintained equal to setup II (0.5–1.0 mm), while the flow rate fed to each column was decreased to 1.63 L h^{-1} , to assess the role of contact time in the NH_4^+ adsorption process.

From the data reported in Fig. 5, it is worth noting that the cumulative NH_4^+ adsorbed reached a value close to 1000 mg NH_4^+ adsorbed kg^{-1} zeolite after 250 h of flushing. In addition, the hourly adsorbed NH_4^+ showed an increasing trend in the first 30 h of flushing, reaching a maximum value close to 10 NH_4^+ adsorbed kg^{-1} zeolite h^{-1} . Compared to the results achieved with setup II (Fig. 4), the decreased flow rate (corresponding to an increased contact time) increased the overall amount of the adsorbed NH_4^+ , but with a lower adsorption rate, likely related to a lower (NH_4^+) loading rate to the columns.

This behaviour was well in line with the study of Sundhararasu et al. (2022), who found that the higher the flow rates, the greater the amount of NH_4^+ passing the adsorbent, allowing zeolite to reach saturation sooner. The results of this study fit with those of Sundhararasu et al. (2022) and suggested that zeolite saturation with NH_4^+ is reached sooner by increasing the flow rate (setup II) because of the high amount of NH_4^+ passing through the adsorbent. This provides for a sharper adsorption curve. With the lower flow rate (setup III), NH_4^+ had a higher time to diffuse within zeolite pores due to the increased residence time. Therefore, (NH_4^+) ions were allowed to approach a higher number of binding sites in the adsorbent material.

3.4. Adsorption kinetics

The adsorption of NH_4^+ ions by zeolites was studied at different time intervals in three experimental setups (Fig. 6). The experimental data points were studied by applying two models to study adsorption kinetics, eqs. (1) and (2), respectively. According to the experimental results, the sorption process can be described as pseudo-first-order reactions, with a single adsorption constant (k_1) calculated using eq. (1), suggesting a single NH_4^+ sorption mechanism. However, unlike the application of eq. (1), which provided a good fit, the application of eq. (2) did not yield a satisfactory fitting (Table 2).

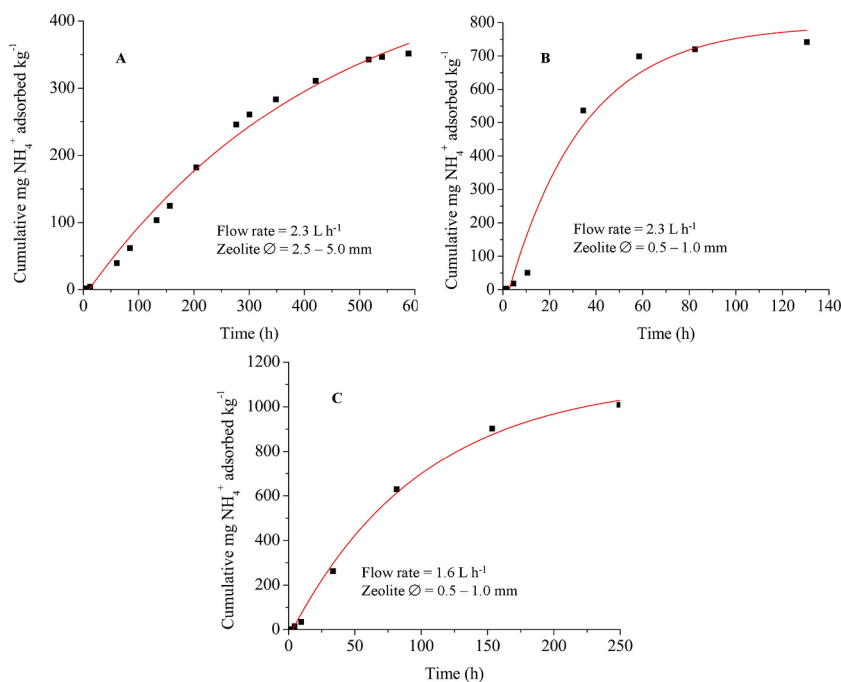


Fig. 6. Kinetic fitting curves of the experimental points obtained, following the application of pseudo first order model (equation (1)), to data attained with setup I (A), II (B) and III (C).

Table 2

Parameter values obtained from applying pseudo-first and pseudo-second order to experimental data of NH_4^+ adsorption by zeolite in pilot scale plant. R^2 , correlation coefficient; χ^2 , chi-square; SSE, residual sum of squares error MSE, mean sum of squares error.

Pseudo first-order model	R^2	χ^2	SSE	MSE	k_1	q_e (mg L^{-1})
SETUP I	0.988	35	3199	200	0.002	531
SETUP II	0.953	210	35595	4449	0.03	814
SETUP III	0.992	85	9065	1133	0.009	1153
Pseudo-second order model	R^2	χ^2	SSE	MSE	k_2	q_e (mg L^{-1})
SETUP I	0.984	47	4148	259	0.00002	736
SETUP II	0.939	237	47397	5924	0.00002	1127
SETUP III	0.988	100	13533	1691	0.000004	1672

The experimental data showed good agreement with the proposed model. As indicated by Muscarella et al. (2023b), the results suggest that the NH_4^+ adsorption process by zeolite involves a mechanism that can be attributed to either ion exchange or adsorption. Among these mechanisms, ion exchange appears to be the most plausible explanation.

This is because the tested zeolites, treated with RDTWW (a solution similar to a salt solution), undergo a pre-treatment process that saturates the negative charges of the zeolite with exchangeable cations. As a result, these exchangeable cations can be easily replaced by NH_4^+ ions. Moreover, the observed ion exchange mechanism in this column study may be associated with other co-existing cations competing for adsorption sites, as suggested by Jiang et al. (2018). Additionally, kinetic adsorption models are essential for understanding the adsorption process, optimizing conditions, and selecting the appropriate adsorbent material to achieve desired adsorption levels in the shortest time. The presented data shows the time required for each setup to reach a plateau in terms of cumulative adsorption of NH_4^+ kg^{-1} and the corresponding adsorption levels at that point. The plateau in the three experimental setups was reached after 589 h, 131 h, and 250 h in setups 1, 2, and 3, respectively. The first setup took the longest (589 h) to reach the plateau, with a cumulative adsorption of 350 $\text{mg NH}_4^+ \text{kg}^{-1}$. On the other hand, the second setup reached the same adsorption level (350 $\text{mg NH}_4^+ \text{kg}^{-1}$) much earlier, after only 20 h, while the third setup reached it after 45 h.

The difference in the time taken to reach the same adsorption level can be attributed to particle size and flow rate (Han et al., 2019). In setups II and III, zeolite with smaller particle sizes was used, providing a larger surface area than larger particles. In contrast, the setup I had slower kinetics due to the use of larger particles with a smaller surface area, resulting in a slower adsorption rate. The flow rate affects the contact time between NH_4^+ and zeolite during the adsorption process. A higher flow rate can facilitate a more rapid exchange of cations on the surface, leading to faster saturation. Combining the effects of particle size and flow rate, setup II demonstrated higher efficiency in reaching the desired adsorption level earlier. This efficiency is crucial in practical applications where time and resources are critical factors.

4. Conclusions

This study investigated the effect of zeolite particle diameter (0.5–1.0 mm and 2.0–5.0 mm) and influent flow rate (1.6 and 2.3 L h^{-1}) on NH_4^+ adsorption from real domestic treated wastewater. Findings revealed that maximum NH_4^+ recovery (49%) and adsorption rate can be achieved by using zeolite with the smallest particle diameter (0.5–1.0 mm) and the highest influent flow rate (2.3 L h^{-1}). The maximum NH_4^+ adsorption rate was 1.2, 21 and 9.8 $\text{mg NH}_4^+ \text{kg}^{-1} \text{h}^{-1}$ after 205, 32 and 35 h of operation. NH_4^+ adsorption rate data were analysed by fitting them to both pseudo-first and pseudo-second-order kinetic models. The former best-approximated NH_4^+ adsorption data thus suggests that the amount of NH_4^+ adsorbed depended solely on the amount of NH_4^+ in contact with the zeolite surface. The current study successfully established the application of a zeolite-packed column in the removal of NH_4^+ from domestic wastewater and the impacts of process parameters.

CRedit authorship contribution statement

Sofia Maria Muscarella: Writing – original draft, Visualization, Methodology, Investigation. **Vito Armando Laudicina:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources. **Daniele Di Trapani:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources. **Giorgio Mannina:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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