



# Journal of Environmental Science and Technology

ISSN 1994-7887

**science**  
alert

**ANSI***net*  
an open access publisher  
<http://ansinet.com>

## Ammonium Ion Removal from Wastewater by a Natural Resin

H. Moazed

Department of Irrigation and Drainage Engineering,  
Faculty of Water Sciences Engineering, Shahid Chamran University of Ahvaz,  
Ahvaz, Khuzestan, Iran

---

**Abstract:** A natural resin, Clinoptilolite, in the powder form was used in this study to remove ammonium ions from synthetic wastewaters. The concentrations of the ammonium ion ( $\text{NH}_4^+$ ) in the synthetic wastewaters were 5, 10, 20, 30 and 40  $\text{mg L}^{-1}$ . Based on the batch kinetic experiments, the equilibrium time was determined to be one hour for synthetic wastewaters of 5, 10, 20 and 30  $\text{mg L}^{-1}$  and 2 h for 40  $\text{mg L}^{-1}$  ammonium ion concentrations. Batch adsorption studies were conducted using 40  $\text{mg L}^{-1}$  ammonium ion solution and 1, 3, 5, 7 and 10 mg Clinoptilolite per 100 mL wastewater at room temperature. The experiments were conducted up to equilibrium time. The removal efficiencies obtained ranged from 68 to 92%, depending on the mass of Clinoptilolite used. Batch adsorption studies also indicated that the most applicable model for the sorption of ammonium ions from the synthetic wastewater with 40  $\text{mg L}^{-1}$  ammonium ion concentration was the Freundlich isotherm model. Results of the study showed that powdered Clinoptilolite could be used in the removal of ammonium ions from synthetic wastewaters with high removal efficiency.

**Key words:** Ammonium ions, Clinoptilolite, natural resin, kinetic models, isotherm models, wastewater treatment

---

## INTRODUCTION

Ammonia is one of the major pollutants that is introduced into receiving natural waters by industrial, domestic and agricultural wastewater discharges. Usually, a low ammonia concentration is desirable in final effluents for two reasons: (1) it is toxic to fish at concentrations greater than about 3  $\text{mg L}^{-1}$  and (2) it will be bio-oxidized by nitrifying microorganisms to nitrite and nitrates. Nitrates and nitrites are undesirable to humans. The nitrate ion standard is equal to or less than 10  $\text{mg L}^{-1}$  as N. A nitrate ion concentration more than the recommended standard can cause the disease methemoglobinemia to occur among infants. Also, nitrates are undesirable in natural waters, because they are nutrients that stimulate algal and aquatic growth (Reynolds and Richards, 1996). Ammonia removal from water may be accomplished by physical, chemical and biological means. Physical operations used to remove ammonia consist of induced-draft stripping towers and spray ponds; chemical methods include breakpoint chlorination and ion exchange. The removal of ammonia by biological means is a two-step process: in the first step, ammonia is converted aerobically to nitrate (nitrification) and in the second step, nitrates are converted to nitrogen gas (denitrification) (Metcalf and Eddy Inc., 1991).

Ion Exchange is a unit process in which ions of a given species are displaced from a solid material or adsorbent by different ions in solution. In this process, undesirable ions such as  $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{Fe}^{+2}$  and  $\text{NH}_4^+$  are removed from water and wastewater (Tchobanoglous and Schroeder, 1987). In ammonia removal from water and wastewater by ion exchange, the ion that is displaced varies with the nature of the solution used to regenerate the bed (Metcalf and Eddy Inc., 1991).

Natural and synthetic resins have been used in the past in the removal of ammonium ion and heavy metals from water and wastewater successfully. Rengaraj and Moon (2002) studied the ability of two synthetic resins in adsorbing cobalt from water and wastewater. They found the adsorption equilibrium time to be 4 h, the adsorption data fitted both the Freundlich and the Langmuir isotherms and resins very effective in ammonium removal. Gisvold *et al.* (2000a, b) found natural resin (zeolite) filters effective in increasing removal efficiency of ammonium from water. Liberti *et al.* (1981) in a pilot study showed that Clinoptilolite was able to remove ammonium and phosphorous from sea water. Booker *et al.* (1996) studied ammonium removal from wastewater sludge by a variety of resins in a batch system and found that sodium resins had the highest capacity in the removal of ammonium. They also found that ammonium sorption was very high at the very beginning (first 10 min) of the experiment. Rozic *et al.* (2000) studied the removal of ammonium ions from water by Clinoptilolite in a batch system and found the equilibrium time for adsorption to be one hour. Chung *et al.* (2000) studied the removal of ammonium ions from industrial wastewaters by powdered Clinoptilolite and obtained 88 to 92 percent removal efficiency. Jorgensen and Weatherly (2002) studied the adsorption of ammonium by the Clinoptilolite in the presence of organic compounds and found that the presence of such compounds increased the adsorption of ammonium. Emadi *et al.* (2001) in a research work found that Clinoptilolite was a better adsorbent for ammonium than activated carbon and that the ammonium ions decreased by 58-80% after 24 h by the Clinoptilolite. Ames (1967) used Clinoptilolite for the removal of ammonium from wastewater and obtained 93-98% removal efficiency. Sanks (1978), Lahav and Green (1998, 2000) and Celik *et al.* (2001) found Clinoptilolite an effective resin in the removal of ammonium ions from water and wastewater.

The hypotheses of using Clinoptilolite for ammonium ion removal in the present study were: (1) it has a greater affinity for ammonia ions than other exchange media and (2) it is relatively inexpensive when compared to other synthetic media (Metcalf and Eddy Inc., 1991). The objectives of the study were: (1) to investigate the potential of the Clinoptilolite in the removal of ammonium ions from synthetic wastewaters, (2) to determine the adsorption equilibrium time, (3) to determine the appropriate adsorption isotherm model, (4) to determine the optimum adsorbent dosage and (5) to design a batch system for treating wastewater. The scope of the investigation include kinetic and batch studies to evaluate the sorption capacity of the aforementioned material.

## MATERIALS AND METHODS

The study was conducted in the water quality laboratories of Shahid Chamran University and Khuzestan Water and Power Authority (KWPA) located in the Ahvaz City, South of Iran, from December 2004 to December 2005.

### **Clinoptilolite**

The Clinoptilolite used in the study was in the powdered form (<0.06 mm) mined by Afrand Touska Inc., Tehran, Iran. The physical and chemical properties of the used Clinoptilolite are shown in Table 1.

### **Ammonium Solutions**

Synthetic wastewaters of 5, 10, 20, 30 and 40 mg L<sup>-1</sup> ammonium ion concentrations were used in the study. At first, a stock solution of 1000 mg L<sup>-1</sup> ammonium ion was prepared in the laboratory using ammonium chloride salt and then, synthetic wastewaters of different ammonium ion concentrations were made from the stock solution. The pH of all synthetic wastewaters was adjusted at 9.5 with 0.025 N sodium hydroxide and 0.025 N sulfuric acid solutions.

Table 1: Physical and chemical properties of Clinoptilolite

Properties	Values
<b>Physical properties</b>	
Particle size (mm)	<0.06
Moisture content (%)	11.24
Specific gravity	0.90
Bulk density (kg m <sup>-3</sup> )	2.60
<b>Chemical properties (%)</b>	
Solubility in water	6.40
Solubility in acid	8.88
Solubility in alcohol	/3.91
Ash	28.23

### Batch Kinetic Studies

Batch kinetic studies were conducted at pH 9.5 (optimum pH). The pH of the solutions was adjusted using 0.025 N sodium hydroxide and 0.025 N sulfuric acid solutions. The experiments were conducted using a rotary shaker apparatus at a room temperature of 21±0.5°C. Clinoptilolite samples in the amount of 5 g/100 mL synthetic wastewaters of 5, 10, 20, 30 and 40 mg L<sup>-1</sup> ammonium ion concentrations were mixed at 125 rpm to determine equilibrium time. Samples were withdrawn at different time intervals (10, 30, 60, 90, 120 and 180 min) up to the equilibrium time. Then, the slurry was centrifuged for 30 min and filtered to separate Clinoptilolite and ammonium-containing waste. The filtrate was used for ammonium ion measurement by the Titration Method. Control samples were run without the Clinoptilolite in all studies. Experiments were repeated three times and the average values were used in the calculations.

### Batch Isotherm Studies

After kinetic studies and determining the equilibrium time, batch isotherm studies were conducted at room temperature (21±0.5°C) by varying the mass of Clinoptilolite. Representative masses (1, 3, 5, 7 and 10 g) of powdered Clinoptilolite were mixed with 100 mL of the solution containing 40 mg L<sup>-1</sup> ammonium ion at 125 rpm for two hours, which was the equilibrium time for Clinoptilolite and ammonium ion reaction mixture. The initial pH of the ammonium ion solutions was adjusted to an optimum of 9.5 with 0.025 N sodium hydroxide and 0.025 N sulfuric acid solutions. The experiments were repeated three times. At the end of the equilibrium time, all the samples were withdrawn, centrifuged for 30 min, filtered and analyzed for the ammonium ion concentration.

## RESULTS AND DISCUSSION

### Batch Kinetic Studies

Based on the batch kinetic studies, the equilibrium time was found to be one hour for synthetic wastewaters of 5, 10, 20 and 30 mg L<sup>-1</sup> ammonium ion concentration and two hours for synthetic wastewater with ammonium ion concentration of 40 mg L<sup>-1</sup> and 5 g Clinoptilolite (Fig. 1). These values for equilibrium time are in agreement with the results obtained by Rozic *et al.* (2000) and in contradiction to the findings of Rengaraj and Moon (2002). The ammonium ion concentration decreased sharply at the very beginning of adsorption, indicating a rapid sorption rate and then, the decrease became marginal, indicating a very slow sorption rate which is in agreement with the findings of Booker *et al.* (1996). The ammonium ion removal efficiency of 95% was obtained at the equilibrium time for the 40 mg L<sup>-1</sup> synthetic wastewater and Clinoptilolite. The synthetic wastewater with 40 mg L<sup>-1</sup> ammonium ion concentration and the equilibrium time of two hours was chosen for the rest of the experiments.

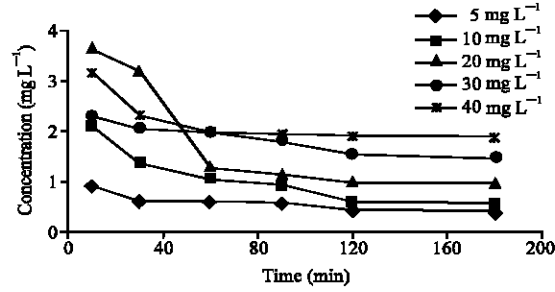


Fig. 1: Ammonium ion concentration versus time for various synthetic wastewaters

The rate equation for the kinetics of adsorption of a solute from a liquid solution is given by Lagergren (1989). It may be represented by:

$$\frac{dq_t}{dt} = k(q_e - q_t) \quad (1)$$

Where:

$q_e$  = Amount of solute sorbed at equilibrium time ( $\text{mg g}^{-1}$ )

$q_t$  = Amount of solute sorbed at time  $t$  ( $\text{mg g}^{-1}$ )

$k$  = Equilibrium rate constant of sorption ( $\text{h}^{-1}$ )

Integrating Eq. 1 for the boundary conditions,  $t = 0$  to  $t = t$  and  $q_t = 0$  to  $q_t = q_t$  gives (Ho and McKay, 1999):

$$q_t = q_e - q_e \exp(-kt) \quad (2)$$

which is the integrated rate law for a pseudo-first order reaction.

Eq. 2 can be linearized as:

$$\ln(q_e - q_t) = \ln(q_e) - kt \quad (3)$$

Recently, the kinetics of adsorption of heavy metals on peat has been described by a pseudo second-order reaction rate equation given by Ho *et al.* (1996):

$$\frac{t}{q_t} = \frac{1}{2k'q_e^2} + \frac{t}{q_e} \quad (4)$$

Where,  $k'$  is the second-order reaction rate constant for adsorption ( $\text{g mg}^{-1} \text{h}^{-1}$ ).

The Lagergren (1989) and Ho *et al.* (1996) kinetic models are now widely used in the analysis of kinetics of adsorption of various substances by varieties of adsorbents. It was therefore decided to examine whether these two models would be applicable in this study.

The batch kinetic data were fitted to the Lagergren (1989) and Ho *et al.* (1996) models by linear regression analysis. Although both models adequately described the kinetic data at 95% confidence level, the Ho *et al.* (1996) model best described the kinetic data with higher R-value ( $R = 1$ ) compared to the Lagergren model ( $R = 0.96$ ). Parameters calculated for the adsorption of ammonium ions onto Clinoptilolite using the Lagergren and Ho's models are shown in Table 2.

Table 2: Parameters calculated using Lagergren's and Ho's models for the sorption of 40 mg L<sup>-1</sup> ammonium ion solution onto Clinoptilolite

Model type	k (1 h <sup>-1</sup> )	q <sub>e</sub> (mg g <sup>-1</sup> )	R	Observed q <sub>e</sub> (mg g <sup>-1</sup> )
Lagergem's model	1.90	0.06	0.96	1.91
Ho's model	41.49	1.91	1.00	1.91

Table 3: Ammonium ion concentrations and removal efficiencies using isotherm studies

Parameters	Mass of clinoptilolite (g)				
	1	3	5	7	10
Initial ammonium ion concentration (mg L <sup>-1</sup> )	40.00	40.00	40.00	40.00	40.00
Ammonium ion concentration at equilibrium time (mg L <sup>-1</sup> )	12.65	7.43	3.62	3.49	3.37
Removal efficiency (%)	68.00	81.00	91.00	91.00	92.00

The kinetics of ammonium ion sorption onto Clinoptilolite followed both models. It is likely that for good fit obtained for both models in this case was due to the fact that most of the removal occurred in the rapid sorption phase (Table 3). Based on the correlation coefficient values and test of statistical significance at a 95% confidence level, it was found that both the Lagergren and Ho's models were able to appropriately describe the sorption kinetics of ammonium ions onto Clinoptilolite. The Ho model predicted higher value for q<sub>e</sub> than the Lagergren model and the q<sub>e</sub> value obtained from the Ho model was exactly the same as the observed value.

To determine the optimum adsorbent (Clinoptilolite) dosage, experiments with influent ammonium concentration of 40 mg L<sup>-1</sup> (determined from the previous section), various amounts (1, 3, 5, 7 and 10 g) of Clinoptilolite and equilibrium time of two hours were conducted. The results showed that with increasing the Clinoptilolite amount, the removal efficiency of ammonium ions increased. However, there were not a considerable difference in the removal efficiency of using 5, 7 and 10 g powdered Clinoptilolite. As a result, usage of 5 g Clinoptilolite per 100 mL wastewater (50 g L<sup>-1</sup>) was determined to be the optimum Clinoptilolite dosage in the study.

### Batch Isotherm Studies

The experimental results from isotherm studies showed that generally, when the mass of the Clinoptilolite was increased, the percentage ammonium ion removal from the synthetic wastewater also increased (Table 3), indicating that the higher the Clinoptilolite to ammonium ion ratio, the greater the adsorption and thus, the removal. The minimum effluent ammonium ion concentration achieved in the study was 3.37 mg L<sup>-1</sup> corresponding to the removal efficiency of 92% after a contact time of 2 h and using 10 g of the powdered Clinoptilolite. Overall, the percentage ammonium ion removal efficiencies ranged from 68 to 92% depending on the mass of Clinoptilolite which is in agreement of the results obtained by Chung *et al.* (2000) and Emadi *et al.* (2001). However, Ames (1967) obtained 93-98 % ammonium removal efficiency from wastewater by the Clinoptilolite. The results showed that powdered Clinoptilolite was a good medium for treating ammonium contaminated waters which is in agreement with the findings of Sanks (1978), Lahav and Green (1998, 2000) and Celik *et al.* (2001).

The most widely used isotherm models are the Langmuir, the Freundlich and the BET models. These models are as follows:

$$\text{Langmuir model} \quad x/m = abC/(1+aC) \quad (5)$$

$$\text{Freundlich model} \quad x/m = kC^{1/n} \quad (6)$$

$$\text{BET model} \quad x/m = ACX_m/(C_s - C)[1 + (A-1)C/C_s] \quad (7)$$

Where:

C = Concentration of solute in solution at equilibrium time (mg L<sup>-1</sup>)

x = Amount of solute adsorbed (mg)

Table 4: Langmuir, Freundlich and BET model equations for ammonium ion adsorption on Clinoptilolite

Model type	Model equation	R
Langmuir	$x/m = [(0.034)/(-0.0099)C]/(1+ 0.034C)$	0.88
Freundlich	$x/m = 0.998C^{1/1666.7}$	0.97
BET	$x/m = (0.629)(0.019)C/\{[1+(0.629-1)C/C_s](C_s-C)\}$	0.17

m = Mass of adsorbent (g)

$X_m$  = Constant related to the amount of solute adsorbed in forming a complete monolayer (mg g<sup>-1</sup>)

$C_s$  = Saturation concentration of solute (mg L<sup>-1</sup>)

A = Constant to describe the energy of interaction between the solute and the adsorbent surface (dimensionless)

a = Constant related to energy or net enthalpy between the adsorbed solute molecule and the adsorbent (L mg<sup>-1</sup>)

b = Mass of adsorbed solute required to completely saturate unit mass of adsorbent (mg g<sup>-1</sup>)

k = Experimental constant indicative of the adsorption capacity of the adsorbent (L g<sup>-1</sup>)

n = Experimental constant indicative of the adsorption intensity of the adsorbent (dimensionless)

The data obtained through isotherm studies were subjected to linear estimation to find the experimental constants (a, b, k, n,  $X_m$  and A) of the above models. The details of the regression equations obtained for the Langmuir, the Freundlich and the BET models for the adsorption of ammonium ion from the 40 mg L<sup>-1</sup> ammonium ion solution by the Clinoptilolite are shown in Table 4.

From the statistical analysis (high value of the correlation coefficient, R) it was found that generally the sorption of the ammonium ions by the powdered Clinoptilolite could well be described by the Freundlich isotherm which is in agreement of the results obtained by Rengaraj and Moon (2002). The values of k and n parameters of the Freundlich model applied to the sorption of the ammonium ions from the synthetic wastewater with 40 mg L<sup>-1</sup> ammonium ion concentration by the Clinoptilolite were 0.998 and 1666.7 L g<sup>-1</sup>, respectively. The high values of k and n parameters showed that both the adsorption capacity and adsorption intensity of the powdered Clinoptilolite for ammonium ions were very high, which was supported by the high removal efficiency of 92% (Table 3). A typical plot of the Freundlich isotherm model applied to the data of sorption of the ammonium ions by the powdered Clinoptilolite is shown in Fig. 2.

Based on the results obtained in the study, the powdered Clinoptilolite can be used as an efficient medium in the removal of ammonium ions from wastewaters in batch systems. Batch adsorption systems, which are mostly operated on a fill-and-draw basis, are suitable for treating small wastewater volumes. If all the wastewater is generated over an 8 to 12 h period, then only one reaction tank will be required. In such situations, once the reaction tank is filled with wastewater, the Clinoptilolite will be added. Then, the mixture will be agitated for a predetermined time (equilibrium time) to enable the system to reach equilibrium. The tank can then be drained and prepared to receive another load of wastewater. In the case of continuously fed wastewater, two vessels may be used in alternated fill-and-draw mode.

By applying the most appropriate adsorption isotherm determined from the previous section (the Freundlich model) to a particular wastewater, it is possible to calculate the amount of the adsorbent (powdered Clinoptilolite) required to reduce the ammonium ions in the wastewater to a desired concentration. The amounts of Clinoptilolite required to achieve 83 to 96% ammonium ion removal from weak (12 mg L<sup>-1</sup>), medium (25 mg L<sup>-1</sup>) and strong (50 mg L<sup>-1</sup>) ammonium ion-containing wastewaters for a daily flow of 150 m<sup>3</sup> day<sup>-1</sup> are calculated based on effluent concentration of 3 mg L<sup>-1</sup> (Table 5). The design is practical except in the case of strong wastewater with 50 mg L<sup>-1</sup> ammonium ion concentration where the Clinoptilolite requirement is excessive. The used Clinoptilolite can then be drained and disposed of in a landfill or used in land farming.

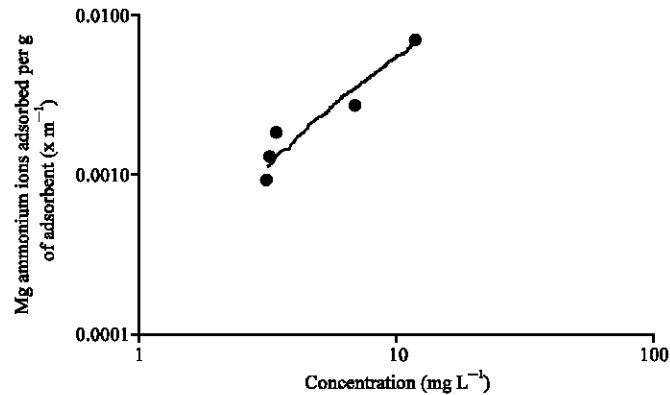


Fig. 2: Freundlich isotherm plot for synthetic wastewater with ammonium ion concentration of 40 mg L<sup>-1</sup> and Clinoptilolite

Table 5: Powdered Clinoptilolite requirements to treat 150 m<sup>3</sup> day<sup>-1</sup> wastewater with various ammonium ion concentrations based on the Freundlich isotherm model

Clinoptilolite required (kg day <sup>-1</sup> )	x/m (mg g <sup>-1</sup> )	Ammonium ion removal efficiency (%)	Ammonium ion concentrations (mg L <sup>-1</sup> )	
			Initial	Final
7064	0.998	96	50	3
3307	0.998	92	25	3
1352	0.998	83	12	3

### CONCLUSIONS

The following conclusions are based on the results obtained in the present study:

- Batch kinetic studies showed that equilibrium time was reached within 2 h of contact between the Clinoptilolite and synthetic wastewater with 40 mg L<sup>-1</sup> ammonium ion concentration.
- The results clearly indicated that both Lagergren (pseudo-first-order) and Ho (pseudo-second-order) models provided realistic description of sorption of ammonium ions onto the Clinoptilolite. However, Ho model predictions of q<sub>e</sub> were higher than those of the Lagergren model. The q<sub>e</sub> value obtained from the Ho model was exactly the same as that of the observed one, while the q<sub>e</sub> value obtained from the Lagergren model was quite different from the observed one.
- The percentage ammonium ion removal from synthetic wastewater with 40 mg L<sup>-1</sup> ammonium ion concentration was up to 92% depending on the mass of Clinoptilolite used. Consequently, the Clinoptilolite could be considered as a good medium for treating wastewaters containing high ammonium ion concentration.
- The isotherm analysis of the data showed that the adsorption pattern for ammonium ions on Clinoptilolite followed the Freundlich isotherm.

### ACKNOWLEDGMENT

The author would like to thank the Khuzestan Water and Power Authority (KWPA) for full financial support for this research through a grant to the author.



## REFERENCES

- Ames, L.L., 1967. Zeolite removal of ammonium ions from agricultural wastewaters. In: Proceedings of the 13th Pacific Northwest Industrial Waste Conference, Washington State University, Ullman, Washington, pp: 135.
- Booker, N.A., E.L. Cooney and A.J. Priestly, 1996. Ammonia removal from sewage using natural Australian zeolite. *Water Sci. Tech.*, 34: 17-24.
- Celik, M.S., B. Ozdemir, M. Turan, I. Koyuncu, G. Atesok and H.Z. Sarikaya, 2001. Removal of ammonia by natural clay minerals using fixed and fluidized bed column reactors. *Water Sci. Tech.*, 1: 81-88.
- Chung, Y.C., D.H. Son and D.H. Ahn, 2000. Nitrogen and organics removal from industrial wastewater using natural zeolite media. *Water Sci. Tech.*, 42: 127-134.
- Emadi, H.J., E. Nezhad and H. Pourbagher, 2001. *In vitro* comparison of zeolite (Clinoptilolite) and activated carbon as ammonia absorbants in fish culture. *Naga, The ICLARM Quality*, 24: 18-20.
- Gisvold, B., H. Odegaard and M. Follesdal, 2000a. Enhanced removal of ammonium by combined nitrification/adsorption in expanded clay aggregate filters. *Water Sci. Tech.*, 41: 409-416.
- Gisvold, B., H. Odegaard and M. Follesdal, 2000b. Enhancing the removal of ammonia in nitrifying biofilters by the use of zeolite containing expanded clay aggregate filter media. *Water Sci. Tech.*, 41: 107-114.
- Ho, Y.S., D.A.J. Wase and C.F. Forster, 1996. Kinetic studies of competitive heavy metal adsorption by sphagnum moss peat. *Environ. Technol.*, 17: 71-77.
- Ho, Y.S. and G. McKay, 1999. The sorption of lead (2) ions on peat. *Water Res.*, 33: 578-584.
- Jorgensen, T.C. and L.R. Weatherley, 2002. Ammonia removal from wastewater by ion exchange in the presence of organic contaminants. *Water Res.*, 37: 1723-1728.
- Lagergren, S., 1989. About the theory of so-called adsorption of soluble substances. *Kungliga Svenska Vetenskapsakademies Handlingar*, 24: 1-39.
- Lahav, O. and M. Green, 1998. Ammonium removal using ion exchange and biological regeneration. *Water Res.*, 32: 2019-2028.
- Lahav, O. and M. Green, 2000. Ammonium removal from primary and secondary effluents using a bioregenerated ion-exchange process. *Water Sci. Tech.*, 42: 179-185.
- Liberti, L., B. Boari, D. Petruzzelli and R. Passino, 1981. Nutrient removal and recovery from wastewater by ion exchange. *Water Res.*, 5: 337-342.
- Metcalf and Eddy Inc., 1991. *Waste water Engineering: Treatment, Disposal and Reuse*. 3rd Edn. McGraw Hill Publishing Co., New York, USA.
- Rengaraj, S. and S. Moon, 2002. Kinetics of adsorption of Co (2) removal from water and wastewater by ion exchange resins. *Water Res.*, 36: 1783-1793.
- Reynolds, T.D. and P.A. Richards, 1996. *Unit Operations and Processes in Environmental Engineering*. PWS Publishing Co., Boston, USA.
- Rozic, M., S. Cerjan-Stefanovic, S. Kurajica, V. Vancina and E. Hodzic, 2000. Ammoniacal nitrogen removal from water by treatment with clays and zeolites. *Water Res.*, 14: 3675-3681.
- Sanks, R.L., 1978. *Water Treatment Plant Design for the Practicing Engineer*. Ann Arbor Science Publishers, Ann Arbor, Michigan, USA.
- Tchobanoglous, G. and E.D. Schroeder, 1987. *Water Quality*. Addison-Wesley Publishing Co., Inc., Massachusetts, USA.