

Reducing Nitrate from Water Using Lanthanum-Modified Adsorbent: Optimization, Thermodynamics, Kinetics, Isotherms

Moradi, Peyman*⁺

*Department of Chemical Engineering, Faculty of Engineering, Kermanshah University of Technology,
Kermanshah, I.R. IRAN*

Qanavati, Ramin; Mirzaei Ghaleh Ghobadi, Masumeh

Department of Chemical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, I.R. IRAN

ABSTRACT: Lanthanum-Modified commercial Activated Carbon (LMAC) adsorbent was synthesized, characterized, and then applied for reducing nitrate from aqueous solutions under various conditions. The extent of nitrate removal depended on four factors: temperature, the aqueous solution pH, initial nitrate concentration, and contact time. The Taguchi approach was used as the method of design for the experiments. Under optimal conditions ($T=300^{\circ}\text{C}$, $\text{pH}=3$, $C_0=10$ ppm, and $t=210$ min), the removal percentages and capacity of nitrate adsorption were found to be 71.31%, and 1.43 for activated carbon (AC) and 93.31%, and 1.87 LMAC, respectively. Thermodynamic parameters, including enthalpy, Gibbs free energy, and entropy, indicated the spontaneous and exothermic nature of the adsorption process. Various isotherms and first and second-order kinetic models were applied to investigate the adsorption process. The pseudo-second-order kinetic model and Langmuir isotherm could well describe the adsorption process.

KEYWORDS: Lanthanum-modified activated carbon; Nitrate adsorption; Taguchi method; Adsorption isotherms; Thermodynamics; Kinetics.

INTRODUCTION

With the expansion of human societies and growing urbanization, the drinking water supply has become one of the most important human challenges, especially in developed countries. Heavy metals and metal cations such as lead, copper, cadmium, chromium, nitrate, and sulfate are among the contaminants with potential damage to the environment which can impose adverse effects on humans,

plants, and animals [1-8]. Among these contaminants, excess nitrate content in the water will make it unusable posing serious concerns around the world [9, 10]. Although the presence of nitrate as a nutrient is essential for the growth of microorganisms and plants, nitrate contamination in surface and groundwater has incremented due to improper treatment of municipal and industrial wastewater

* To whom correspondence should be addressed.

+ E-mail: p.moradi@kut.ac.ir

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and improper use of fertilizers in agricultural lands [11-14]. According to the World Health Organization (WHO), the safe limit of NO_3^- in drinking water is 50 mg/L [15] which may cause side effects on human health, including stomach cancer and methemoglobinemia, a common disease among children [16, 17].

The mentioned problem can be overcome by eliminating nitrate from drinking water sources. Nitrate removal from water has been a challenge due to its high stability and solubility. Several methods have been investigated for nitrate elimination among which dialysis, reverse osmosis, membrane filtration, and biological methods can be named [18-23]. These techniques are, however, expensive. On the other hand, adsorption is a proper, cost-effective, flexible, and feasible separation technique for nitrate removal. The use of suitable adsorbents is a key factor in successful nitrate removal [14, 24-30]. Toxic organic compounds can be eliminated from wastewater using solid adsorbents [31-36]. During the adsorption process, nitrate molecules are physically or chemically adsorbed on the surface active sites of the adsorbent [37-39].

Owing to their high specific surface area, proper adsorption capacity, specific surface reactivity, and microporous structure activated carbon-based adsorbents have gained increasing popularity for removing different substances [40-42]. This class of adsorbents is now widely used in several processes such as purification [43, 44], deodorization, decolorization [45, 46], separation [47, 48], and catalysis [49, 50].

Recently, lanthanum-modified adsorbents have been explored for their efficient phosphates removal [51-55]. Moreover, lanthanum-modified biochar efficiency in the removal of nitrates was also tested [55, 56]. Lanthanum has exhibited high sensitivity and absorption capacity toward phosphate and nitrate, due to the strong attraction between La^{3+} ions and oxygen atoms, especially phosphate ions through the anion-ligand exchange process. Most of the studies in this regard have addressed the use of lanthanum to improve the phosphate removal activity of the adsorbent. A recent study [55] applied pine cone-derived biochar with lanthanum chloride as an efficient biosorbent for removing phosphate and nitrate from water.

In the present work, a commercial activated carbon (AC) was modified by lanthanum nitrate to remove nitrate from aqueous solutions. The present paper presents an

experimental and theoretical investigation of nitrate adsorption by commercial activated carbon and its modified form. Lanthanum-Modified Activated Carbon (LMAC) was synthesized, characterized, and finally compared with Activated Carbon (AC). To complete the study, the adsorption isotherms, thermodynamics, and kinetics were also investigated.

EXPERIMENTAL SECTION

Material & methods

Lanthanum nitrate ($\text{LaN}_3\text{O}_9 \cdot 6\text{H}_2\text{O}$, 99%), hexamethylenetetramine ($\text{C}_6\text{H}_{12}\text{N}_4$) and activated carbon, and sodium nitrate (NaNO_3 , 99%) were purchased from Merck. A sodium nitrate solution (500 mg/L) was synthesized by dissolving 0.677 g of NaNO_3 in DM (demineralized) water; this solution was filled up to the mark of a 1L measuring flask. Lower concentrations of NaNO_3 solutions were prepared by further dilution. Materials were measured using a digital balance with accuracy to 0.001 g. DM water was used throughout the experiment. The applied chemical materials were of analytical grade. Nitrate concentrations in the solution were quantified using an Ultraviolet-Visible spectrophotometer (JENWAY/7315, United Kingdom).

Preparation of adsorbents

For adsorbent preparation, activated carbon was modified with lanthanum nitrate. For this purpose, the activated carbon was first washed with DM water several times before being dried and well-powdered. Next, 3 g of powdered activated carbon was mixed with 5 g of hexamethylenetetramine and 5 g of lanthanum nitrate and transferred to a flask (100 mL), and dissolved in DM water; after that, it was placed in an ultrasonic bath at room temperature for half an hour. Since the reaction between activated carbon, hexamethylenetetramine, and lanthanum nitrate will be well activated at a high temperature, the resulting solution was stirred for 1 hour in an oil bath (80°C). The solution was centrifuged by a glass centrifuge pot at 1500 rpm for 5 min. The supernatants were eliminated by pipette, and the residue was rinsed with DM water, transferred into the beaker, and heated at 90°C for 3 hours to provide a dry adsorbent.

Characterization of Adsorbents

The Morphological properties of the adsorbents

Table 1: Factors and their levels for the design of experiments.

Factor	Level		
	1	2	3
pH	3	7	11
T (°C)	0	30	60
C ₀ (mg/L)	10	25	40
t (min)	30	120	210

Table 2. L9 orthogonal arrays

Run	Factor			
	pH	T (°C)	C ₀ (mg/L)	t (min)
1	3	0	10	30
2	3	30	25	120
3	3	60	40	210
4	7	0	25	210
5	7	30	40	30
6	7	60	10	120
7	11	0	40	120
8	11	30	10	210
9	11	60	25	30

were studied by Scanning Electron Microscopy (SEM) (TESCAN Vega 3). While their specific surface areas were calculated using the Brunauer–Emmett–Teller (BET) equation ((Micromeritics/Gemini-2372).

Design of experiments

Among the effective factors in a process, some of them are more important than others. In the design of experiments, some important information can be identified as the factors with influence the response. Also, the number of required experimental tests will be reduced [57].

Developed by *Genichi Taguchi*, the Taguchi method is a strong approach to designing experiments. The design parameters are the most important part of the Taguchi method which ensures high quality along with the reduced cost. The possibility of conducting experiments in parallel can be considered another advantage of the Taguchi method [57, 58].

QUALITEK-4 (QT4), the Windows version software for the Taguchi method, was used to investigate the following targets of the analysis. The choice of controlling

factors is an important step in the Taguchi method. The design of the factors is generally determined based on the experimenter's experience [59]. 162 experiments were required to optimize the adsorption using the full factorial method which declined to 9 upon using the Taguchi method (the L9 orthogonal array). Three combinations of the variable (levels) were selected for each effective factor of the adsorption process (pH, temperature, initial concentration, and time). The factors and their levels, and the standard L9 orthogonal array is presented in Table 1 and Table 2, respectively.

Adsorption studies

For each adsorbent, nitrate adsorption was studied under nine conditions, derived from the Taguchi approach. NaOH and HCl were used to adjust the solution pH. The temperature was set by putting the beakers in cold and hot containers for providing high and low temperatures. After equilibrium, the samples were filtered, and a UV-Visible spectrophotometer was used to determine the solution adsorption at 220 nm. Nitrate removal can be determined by:

Table 3: BET parameters of AC and LMAC.

Parameter	AC	LMAC
BET [$\text{m}^2 \cdot \text{g}^{-1}$]	1098.8	723.66
Total pore volume [$\text{cm}^3 \cdot \text{g}^{-1}$]	0.6329	0.4308
Average pore diameter [nm]	2.304	2.3811

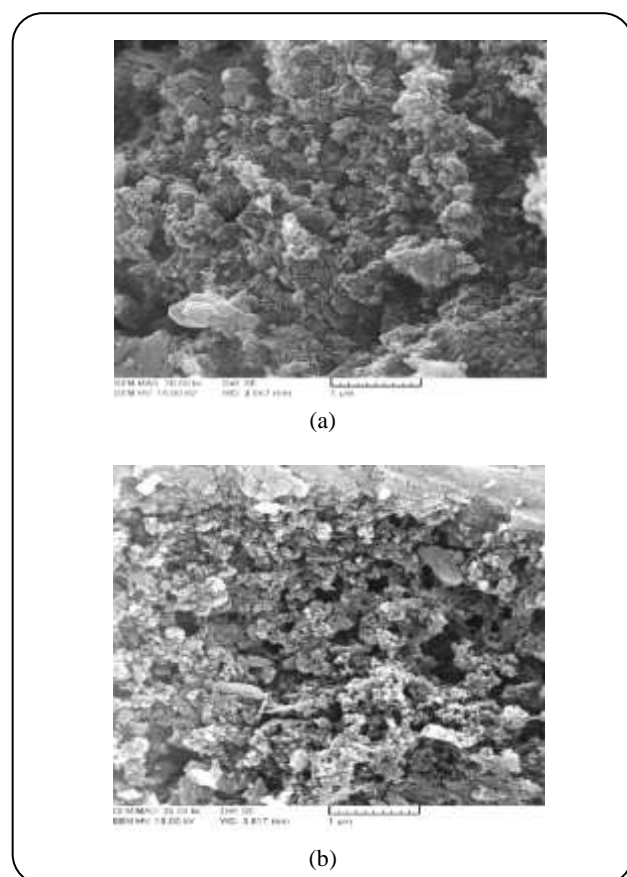


Fig. 1: SEM images of (a) AC and (b) LMAC.

$$\text{Removal (\%)} = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

Where C_0 and C_e are the initial and equilibrium nitrate concentrations in the solutions, respectively.

Adsorption isotherms were also assessed by changing the initial nitrate concentration to 0 °C. The adsorption data were fitted with three adsorption isotherms involving Langmuir, Freundlich, and Temkin. The adsorption isotherm studies were repeated at 30°C and 60°C for both the original and the modified adsorbents.

RESULTS AND DISCUSSION

Characterization

BET results

The specific surface areas of the synthesis adsorbents were calculated using the BET equation. Based on the BET results, the diameter and pore volume of the LMAC were smaller than the commercial adsorbent (AC) due to the activated carbon modification by lanthanum. Lanthanum placement on pores and the surface areas of activated carbon caused the above parameters to decrease; moreover, higher sorption capacities were obtained due to its high adsorbing activity. The BET parameters of the adsorbents are listed in Table 3.

Scanning Electron Microscopy (SEM)

The morphology and size of AC and LMAC adsorbents were studied using SEM. The results (Fig. 1) reveal that this carbon bone is completely uniform, porous, and well-sized. Also, by comparing SEM of activated carbon before and after lanthanum modification, it can be seen that lanthanum is uniformly coated on the surface of the modified adsorbent. Lanthanum spread on the adsorbent which can be easily distinguished by its lighter color.

The weight percentage of adsorbent elements is presented in Table 4. Also, the EDS results of AC and its modified form (LMAC) are depicted in Figs. 2(a) and (b), respectively. A comparison of the EDS results indicates that lanthanum was successfully incorporated into the adsorbent structure and formed bonds with carbon atoms.

Adsorption studies

Regarding the UV absorption ability of nitrate-containing solutions (at 220 nm), the nitrate concentration can be determined by comparing the absorbance of the sample at 220 nm to that of a solution with known nitrate content. Standard solutions containing 5, 10, 15, 25, 30, 35, and 40 ppm of nitrate were prepared and their absorptions were measured at 220 nm.

Tables 5 and 6 show the equilibrium concentrations of nitrate in the solution at various conditions using AC and LMAC, respectively.

Adsorption isotherms

To study the equilibrium adsorption of nitrate ions on the adsorbents (both original and modified), various adsorption isotherm models including Freundlich, Langmuir, and Temkin were examined.

Table 4: The weight percentage of elements in the adsorbents.

Element	w% (AC)	w% (LMAC)
Carbon	86.22	56.33
Oxygen	8.99	22.78
Nitrogen	3.14	9.22
silicon	0.61	-
sulfur	1.03	0.54
Lanthanum	0	11.13
Total	100	100

Table 5: Equilibrium concentrations of nitrate in the solution at the various conditions (AC as the adsorbent).

Run	pH	T	C ₀	t	Results UV	C _e
1	3	0	10	30	0.137	3.667
2	3	30	25	120	0.421	10.430
3	3	60	40	210	0.601	17.768
4	7	0	25	210	0.403	9.977
5	7	30	40	30	0.706	20.852
6	7	60	10	120	0.159	4.254
7	11	0	40	120	0.646	19.082
8	11	30	10	210	0.141	3.777
9	11	60	25	30	0.506	12.527

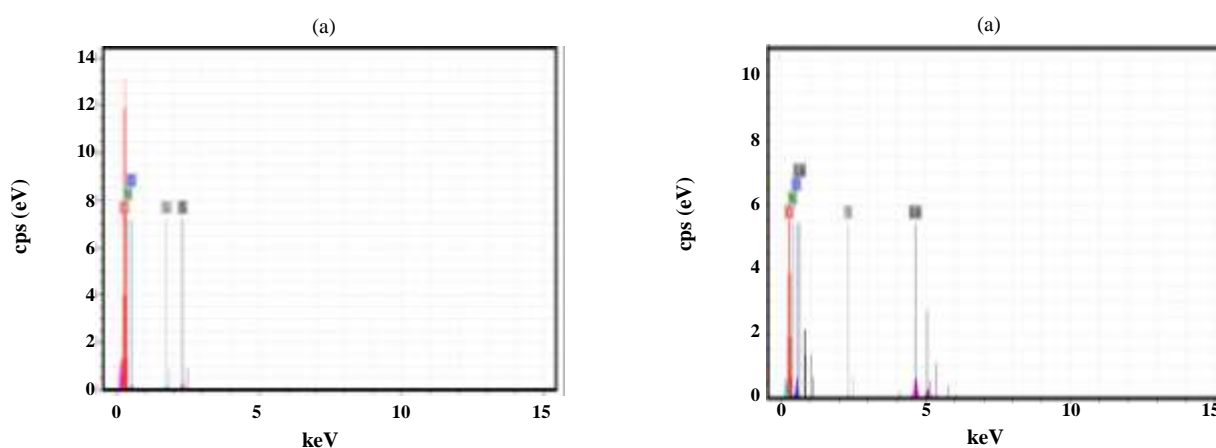
**Fig. 2: EDS results for (a) AC and (b) LMAC.**

Table 6: Equilibrium concentrations of Nitrate in the solution at the various conditions (LMAC as the adsorbent).

Run	pH	T	C ₀	t	Results UV	C _e
1	3	0	10	30	0.041	1.099
2	3	30	25	120	0.23	5.693
3	3	60	40	210	0.364	10.753
4	7	0	25	210	0.137	3.391
5	7	30	40	30	0.428	12.644
6	7	60	10	120	0.109	2.922
7	11	0	40	120	0.256	7.562
8	11	30	10	210	0.077	2.064
9	11	60	25	30	0.362	8.960

To fit the experimental data to the isotherm models, the linear form of Langmuir (Eq. (2)), Freundlich (Eq. (3)), and Temkin (Eq. (4)) [60] were used.

$$\frac{C_e}{q_e} = \frac{1}{Q_{\max} b} + \frac{C_e}{Q_{\max}} \quad (2)$$

$$\text{Log}(q_e) = \text{Log}(K_f) + \frac{1}{n} \text{Log}(C_e) \quad (3)$$

$$q_e = B \ln(A) + B \ln(C_e) \text{ and } B = \frac{RT}{b} \quad (4)$$

In Eq. (2), C_e (mg/L) is the nitrate equilibrium concentration; q_e (mg/g) shows the equilibrium amount of the nitrate; Q_{\max} denotes the maximum capacity of adsorption, and b represents the Langmuir equilibrium constant.

In Eq. 3, K_f = Freundlich adsorption capacity parameter, (mg/g) (L/mg)^{1/n} and $1/n$ = Freundlich adsorption intensity parameter.

In Eq. 4, A shows the maximum binding energy also called as Temkin isotherm equilibrium binding constant (L/g); B represents a constant corresponding to the sorption heat (J/mol); R is the universal gas constant (8.314 J/mol/K); T denotes the absolute temperature (298 K), and b is a constant indicating the adsorption power of the adsorbent [61].

The regression coefficients (R^2) of AC and LMAC are listed in Tables 7 and 8, respectively. The mean R^2 at 0, 30, and 60 °C for Langmuir, Freundlich, and Temkin models were 0.99, 0.97, and 0.95 for AC, respectively,

while the mean R^2 at 0, 30, and 60 °C for Langmuir, Freundlich and Temkin models were 0.99, 0.95, and 0.93 for LMAC, respectively. The results showed that the Langmuir model was best fitted to the experimental absorption data ($R^2 = 0.99$) indicating that the adsorption mechanism was monolayer [62]. The results of other studies on lanthanum-modified adsorbents are consistent with the result in this section [63].

Analysis of ANOVA under Taguchi design

After designing experiments using the Taguchi approach, ANOVA was applied to study the experimental data and find the optimum levels. Tables 9 and 10 represent the degree of freedom (DOF), the sum of squares (S), pure sum (S'), and percent P(%) at optimum conditions or any possible condition for nitrate adsorption on AC and LMAC. Optimum conditions were determined based on the qualified character. For each factor, the degree of freedom was listed in the DOF_R column. Each column of Tables 9 and 10 illustrates the effectiveness of each factor on nitrate adsorption in comparison with other factors and analyzes these data with a statistical approach. The contribution of each parameter to total dispersion in the adsorption process was analyzed as shown in Fig. 3. According to Tables 9 and 10 and Fig. 3, the temperature is the most effective factor (75%) in the adsorption process using AC; while in the case of LMAC, the initial concentration played the most effective role (50.7). The effects of other factors are presented in Fig. 3.

Table 7: Regression coefficients (R^2) obtained from Langmuir, Freundlich and Temkin isotherms for AC.

Isotherm Model	Langmuir	Freundlich	Temkin
Temperature ($^{\circ}\text{C}$)	R^2	R^2	R^2
0	0.9992	0.9925	0.9948
30	0.9945	0.9725	0.9991
60	0.9838	0.9614	0.8506
Mean	0.9925	0.9755	0.9482

Table 8: Regression coefficients (R^2) obtained from Langmuir, Freundlich and Temkin isotherms for LMAC.

Isotherm Model	Langmuir	Freundlich	Temkin
Temperature ($^{\circ}\text{C}$)	R^2	R^2	R^2
0	0.9982	0.9729	1
30	0.9999	0.9740	0.9995
60	0.9651	0.9113	0.7759
Mean	0.9877	0.9527	0.9251

Table 9: ANOVA-nitrate adsorption on AC.

Factor	DOF(f)	Sum of Sqrs. (S)	Variance (V)	F-Ratio (F)	Pure Sum (S')	Percent P(%)
pH	2	38.92	19.46	-	38.92	7.786
T	2	374.791	187.395	-	374.791	74.982
C_0	2	46.375	23.187	-	46.375	9.278
t	2	39.754	19.877	-	39.754	7.953
Other /Error	0					
Total	8	499.841				100.00%

Table 10: ANOVA-nitrate adsorption on LMAC.

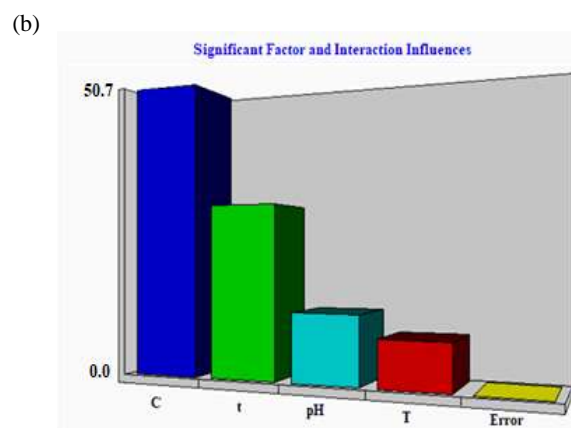
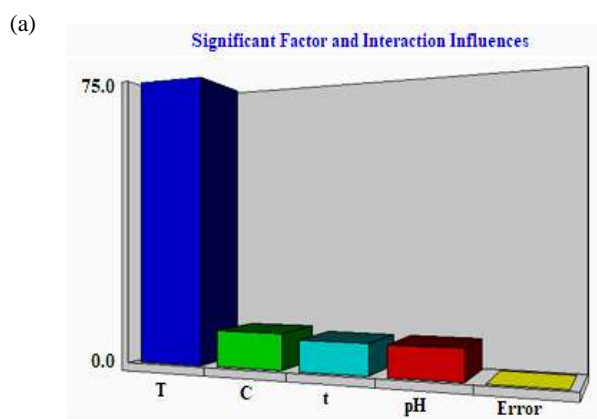
Factor	DOF(f)	Sum of Sqrs. (S)	Variance (V)	F-Ratio (F)	Pure Sum (S')	Percent P(%)
pH	2	28.677	14.338	-	28.677	11.707
T	2	19.324	9.662	-	19.324	7.889
C_0	2	124.12	62.06	-	124.12	50.673
t	2	72.82	36.41	-	72.82	29.729
Other /Error	0					
Total	8	244.942				100.00%

Table 11: Optimum conditions for obtaining the highest removal percent of nitrate using AC.

Factor	Level Description	Level	Contribution
pH	3	1	2.935
T	0	1	8.672
C ₀	10	1	2.885
t	210	3	2.772
Total contribution from all factors			17.263
Current grand average of the performance			57.811
The expected result at the optimum conditions			75.075

Table 12: Optimum conditions for obtaining the highest removal percent of nitrate using LMAC.

Factor	Level Description	Level	Contribution
pH	3	1	2.408
T	0	1	1.892
C ₀	10	1	4.665
t	210	3	3.628
Total contribution from all factors			12.592
Current grand average of the performance			84.701
The expected result at the optimum conditions			97.294

**Fig. 3: Contribution of each parameter on total dispersion in the adsorption process using adsorbent: a) AC b) LMAC.****Optimization conditions**

Numerical investigations of the Taguchi design were applied for nitrate adsorption on AC and LMAC and imported to Qualitek-4 to find the optimal condition of variables to obtain the highest removal percent in the adsorption of nitrate (Tables 11 and 12). The optimum point was found to be at levels 3, 1, 1, and 1 of pH, T, C,

and t, respectively. These values corresponded to the temperature of 0 °C, the concentration of 10 ppm, and the processing time of 210 for nitrate adsorption onto both adsorbents. At the optimum condition, the Taguchi approach predicts that the removal percent of nitrate is 75.075 % and 97.294 % (see the last row in Tables 11 and 12) for AC and LMAC, respectively. To validate the accuracy

Table 13: Thermodynamic constants for the adsorption of nitrate.

T (K)	ΔH° (kJ/mo)	ΔG° (kJ/mo)	ΔS° (kJ/(mol.K))
273.15	-8.097	-1.5642	-0.0242
303.15		-0.6062	
333.15		-0.1123	

of the model proposed by Taguchi method, the additional adsorption experiments were conducted at the optimum conditions which resulted in removal percentages and nitrate adsorption capacity of 71.31%, and 1.43 for AC and 93.31% and 1.87 for LMAC, respectively indicating the high accuracy of the method.

Thermodynamic parameters

Thermodynamic parameters including standard enthalpy change (ΔH°), entropy change (ΔS°), and the Gibbs free energy change (ΔG°) were determined to evaluate the spontaneous nature and thermodynamic behavior of nitrate adsorption. ΔG° can be determined by the following formula [64]:

$$\Delta G^\circ = -RT \ln K_c \quad (5)$$

Where R is the ideal gas constant (8.314 J/(mol.K)), T represents the temperature in Kelvin, and K_c shows the adsorption equilibrium constant, defined as [64, 65]:

$$K_c = \frac{C_a}{C_e} \quad (6)$$

Where C_e and C_a are the equilibrium concentration values in the solution (mg/L) and the adsorbent (mg/L), respectively.

Values of the ΔH° and ΔS° can be also determined by:

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (7)$$

The results of thermodynamic constants at different temperatures for the adsorption process are listed in Table 13.

The ΔH° value for nitrate adsorption was -8.097 kJ/mol. This negative value indicated the exothermic nature of the process [64]. Regarding the negative ΔG° values, the nitrate adsorption was spontaneous under the experimental conditions. ΔG° decreased by declining

the temperature, reflecting the high efficiency of the adsorption process at low temperatures. The negative value of ΔS° also showed the affinity of nitrate on the adsorbent, thereby indicating certain structure variations in the adsorbent and decreasing the interface randomness between the adsorbent and aqueous solution [64, 66].

Adsorption Kinetics

To study the adsorption kinetics of nitrate onto AC and LMAC, the pseudo-first-order and second-order kinetic models were applied to the experimental data. The pseudo-first-order kinetic model is generally defined as [67]:

$$\frac{dq_t}{dt} = k_1 (q_e - q_t) \quad (8)$$

where k_1 (min^{-1}) is a rate constant of the kinetic model while q_t (mg/g) and q_e (mg/g) show the adsorption capacities at time t (min) and equilibrium, respectively. By integrating Eq. (8), another form of this kinetic model can be obtained as follows:

$$\log (q_e - q_t) = \log(q_e) - k_1 t / 2.303 \quad (9)$$

The plot of $\log (q_e - q_t)$ vs t gives a linear relationship whose intercept shows q_e [Eq. (9)]. The pseudo-second-order kinetic model is described by the following reaction [67]:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (10)$$

Where k_2 [g/(mg.min)] is the equilibrium rate constant. The plot of (t/q_t) vs (t) offers a linear relationship whose slope signifies q_e [Eq. (10)]. The results of applying kinetic models to nitrate adsorption on AC and LMAC are shown in Figs. 4 and 5, respectively. The adsorption capacities at equilibrium (q_e) and correlation coefficients for nitrate AC and LMAC are also tabulated in Table 14. These results indicated a better fitting of the pseudo-second-order kinetic model (with $R^2=0.998$) for both adsorbents as compared to the first-order model (with $R^2=0.86$). Moreover, q_e values obtained from the pseudo-second-order model are very close to the experimental data for adsorption on AC and LMAC while those derived from the pseudo-first-order model are far different from the experimental data (see Table 14).

Table 14. Comparison between the experimental and calculated q_e values for the nitrate adsorption on AC and LMAC using the first and second-order adsorption kinetics

Adsorbent	$q_{e, \text{exp.}}$ (mg/g)	Pseudo-first order equation		Pseudo-second order equation	
		$q_{e, \text{cal.}}$ (mg/g)	R^2	$q_{e, \text{cal.}}$ (mg/g)	R^2
AC	1.43	0.685	0.8652	1.46	0.9985
LMAC	1.87	0.78	0.867	1.92	0.9981

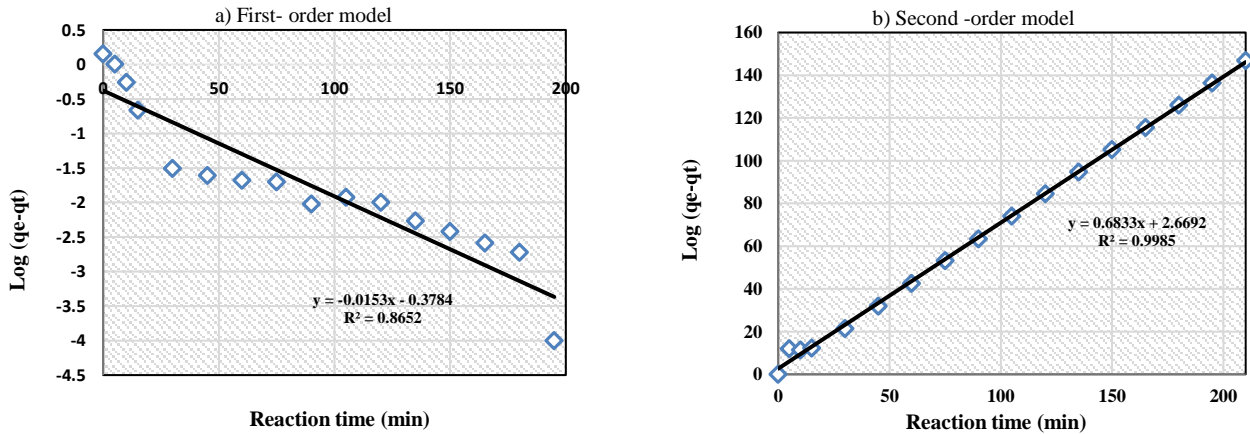


Fig. 4: Kinetic models for the adsorption of nitrate on AC.

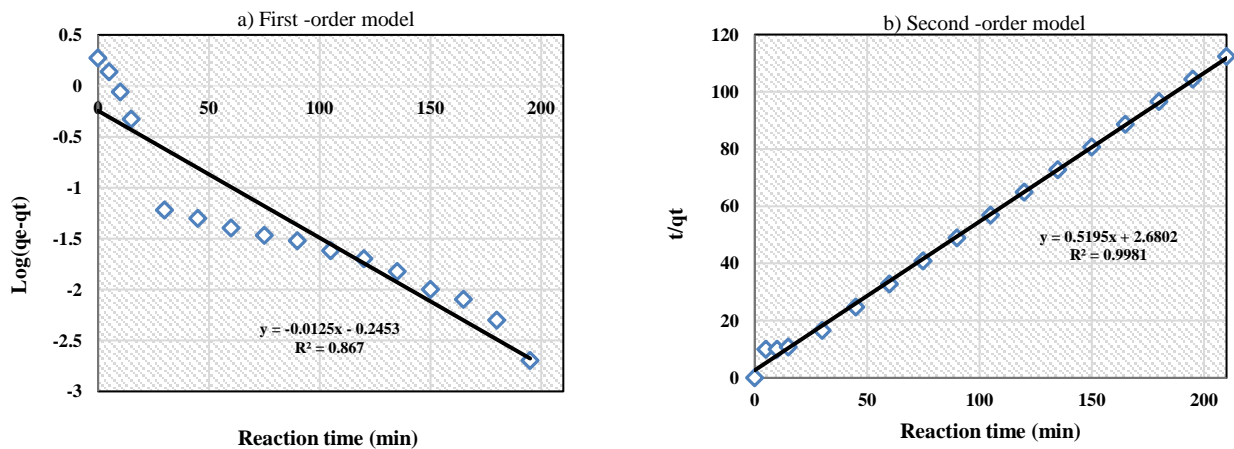


Fig. 5: Kinetic models for the adsorption of nitrate on LMAC.

Comparison AC and LMAC with other adsorbents

A comparison of the adsorption capacity of nitrate using various materials is presented in Table 15. As shown, LMAC has a high adsorption capacity for removing nitrate introducing LMAC as a potent adsorbent for reducing nitrate in aqueous solutions. However, due to the use of high-concentration nitrate solutions compared to the present study, some of the materials listed in the table

showed a higher adsorption capacity than the adsorbent prepared in the present work.

CONCLUSIONS

The activated carbon (AC) and synthesis lanthanum nitrate/activated carbon (LMAC) adsorbents were investigated for removing nitrate from aqueous solutions. Under the optimum conditions ($T= 30^{\circ}\text{C}$, $\text{pH}=3$, $C_0=10$ ppm,

Table 15: Comparison of nitrate removal performance of different adsorbents.

Adsorbent type	Adsorption capacity	Concentration (ppm)	Contact time	Temperature (°C)	pH	Ref.
Carbon nanotubes	25 mmol/g	--	60 min	25	<5.0	[68]
Pure alkaline lignin	1.8 mmol/g	1–30	48 h	30	--	[69]
La-pine cone biochar	25.8mg/g	200	90-120 min	20	.7	[55]
Halloysite	0.54 mg/g	100	17 h	Room temperature	5.4	[70]
Bamboo powder charcoal	1.25 mg/g	0–10	120 h	10	--	[71]
Commercial activated carbon	1.22 mg/g	0–25	10 min	15	--	[72]
Mustard straw charcoal	1.30 mg/g	0–25	10 min	15	--	[72]
Sepiolite activated by HCl	38.16 mg/g	100	5 min	--	--	[73]
H ₂ SO ₄ treated carbon cloth	2.03 mmol/g	115	60 min	25	.7	[74]
AC	1.43 mg/g	10	210	.0	3	Present study
LMAC	1.87 mg/g	10	210	.0	3	Present study

and $t = 210$ min obtained from the Taguchi method), the removal percentages and capacity of nitrate adsorption were 71.31% and 1.43 for AC and 93.31% and 1.87 for LMAC, respectively. Among the examined kinetic models, the process followed the pseudo-second-order kinetic model (with $R^2 = 0.99$). The adsorption of nitrate follows monolayer adsorption as indicated by its proper fitting with Langmuir isotherm. The experimental data were used to calculate the thermodynamic parameters (ΔH° , ΔG° , and ΔS°) which showed that the adsorption of nitrate was spontaneous and exothermic. The results derived from the present study suggest that LMAC could be a promising adsorbent for nitrate removal from aqueous solutions.

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