# Nitrate Removal from Aqueous Solutions Using Granular Activated Carbon Modified with Iron Nanoparticles

B. Kamarehie*[a], E. Aghaali[b], SA. Musavi[c], SY. Hashemi[d], A. Jafari[a]

[a] Nutrition Health Research Center, Department of Environment Health, School of Health and Nutrition, Lorestan University of Medical Sciences, Khorramabad, Iran,
[b] Department of Environment Health, Lorestan University of Medical Sciences, Khorramabad, Iran
[c] Department of Environment Health, Faculty of Health, Kermanshah University of Medical Sciences, Kermanshah, Iran
[d] Department of Environment Health, Faculty of Health, Tehran University of Medical Sciences, School of Health, Tehran, Iran

*A B S T R A C T*

Nitrate contamination of water resources and the growing concentration of nitrate endanger human health and the environment and considering its reduction strategies from water resources is important. The aim of this study was to investigate the possibility of removal of nitrate from aqueous solutions using granular activated carbon from grape wood coated with iron nanoparticles. The results showed that more than 99% of the nitrate was removed from the solution using granular activated carbon/nanoparticles zero valent iron (GAC/NZVI). The nitrate adsorption process by GAC followed the Freundlich isotherm ($R^2$ = 0.95) and NZVI and GAC/NZVI followed Langmuir isotherm ($R^2$ = 0.96). Furthermore, the kinetic studies of all three adsorbents for nitrate adsorption showed the highest correlation with the pseudo-second order equation. According to the results of this study, it can be stated that activated carbon derived from grape wood coated by iron nanoparticles as a relatively cheap adsorbent is efficient in nitrate removal from water.

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## 1. INTRODUCTION

In recent decades, the pollution of surface and groundwater resources by nitrate and the rapidly increasing nitrate concentration in these resources has endangered human health and the environment and raised many challenges [1]. The main reasons for increasing the nitrate concentration in water resources, include the use of chemical fertilizers to increase productivity in agriculture, disposal of municipal and industrial wastewater containing nitrate, increase of untreated urban waste leachate, disposal of urban and rural raw sewage and the effluent of septic systems, as well as increase of nitrogen emissions from industries into the atmosphere [1-4].

Increased concentration of nitrate in drinking water, causes environmental problems, a serious threat to aquatic ecosystems, such as eutrophication and growth of algae, reduction of biodiversity and water quality in one hand [5-8] and on the other hand, causes undesirable effects such as occurrence of methemoglobina syndrome (blue baby) in children, increased potential for cancer, increased digestive diseases and abortions, etc. [9, 10]. Due to major problems that increased nitrate concentrations in water creates, the US Environmental Protection Agency (EPA) has set the maximum concentration of nitrate to 50 mg/l and the EU 25 mg/l in drinking water [11, 12].

Nitrate is a highly stable anion with high solubility and a low tendency to absorb in water, which conventional water purification processes (coagulation, flocculation, sedimentation, and filtration) cannot remove it [13]. Other technologies including ion exchange resins [14, 15], reverse osmosis [16], electrochemical removal [17], micro-electrodialysis and micro-electrolysis [2], biological removal of nitrate [1,

*Corresponding Author Email: javdanian@eng.sku.ac.ir* (H. Javdanian)

18], nanofiltration and chemical reduction by iron nanoparticles [5, 19, 20] and adsorption [21-23] have been studied to remove nitrate from water.

Among these methods, adsorption processes have great importance due to the ease of design and operation, high efficiency and economic benefits and low cost [24]. The use of activated carbon as a reliable adsorbent has been proven to remove persistent pollutants from water and wastewater [25]. However, activated carbon performance in different forms of powder and granular is different in order to remove nitrates and studies have shown that nitrate adsorption with activated carbon is appropriate [6, 13]. In general, the physical properties of activated carbon, such as porosity, ratio of surface area and volume, as well as its chemical properties, especially surface functional groups, are very effective in its function and can be improved by modification [26].

Investigating the results of various studies has shown that the modification of chemical properties in comparison with physical properties of activated carbon has a greater effect on its efficiency [21, 27]. Hence, researchers have used different methods to modify the physicochemical properties of activated carbon to enhance adsorption efficiency [28, 29]. The use of different acids and bases for washing, surfactants for modification and various nanoparticles for coating activated carbons are the main methods used to modify and activate the carbon surface [28]. In current study, activated carbon produced from grape wood coated by iron nanoparticles (modified) as a cheap adsorbent was used to remove nitrate from aqueous solutions.

## 2. MATERIALA AND METHODS

Activated carbon was prepared from grape wood. All used chemicals in this study, including iron sulfate ($FeSO_4.7H_2O$), sodium bromide, starch, ethanol and sodium nitrate were purchased from Sigma Aldrich Company. In this work twice distilled water was used to prepare stock and other solutions. 1N sodium hydroxide and sulfuric acid were used to adjust pH. The pH-meter model 50-pp-Sartorious was used to measure the pH values. Also, the adsorbent particles were separated from the solution using the quartz filters and the centrifuge device (Hettich EA20). A UV/Vis spectrophotometer (CE-2021) was also used at 220 nm wavelengths to determine the concentration of nitrate.

### 2. 1. Preparation of adsorbents
**2. 1. 1. NZVI Preparation**      Synthesis of zero valent iron nanoparticles was performed by reducing trivalent iron sulfate to zero valent according to reaction 1.
Reaction 1:
$2FeSO_4 + 6NaBH_4^- + 18H_2O \rightarrow 2Fe^0(s) + 6B(OH)_3 + 21H_2 + 6NaSO_4$
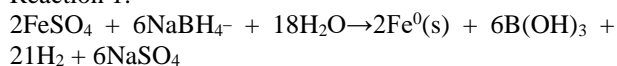
A mixture of 0.1N iron sulfate ($FeSO_4.7H_2O$) solution and ethanol was prepared with a ratio of 3/7 in total volume of 100 ml, and 0.5 g of starch was then added as surfactant to prevent the accumulation of nanoparticles. Then, 50 ml of 0.16 molar $NaBH_4$ (reductant solution) was added gradually (2 ml/min) to the solution under magnetic shaking. Produced black iron nanoparticles were separated by vacuum filtration and washed with water and ethanol (50 ml water and 50 ml ethanol were used for each gram of the nanoparticles).

**2. 1. 2. GAC Preparation**      In order to prepare activated carbon, the wood was prepared from green grape trees in Khorramabad city. The wood was cut to pieces smaller than 2 cm and washed with distilled water several times to remove the impurities. They were then dried for 24 hours at 105 °C and then grinded. The grinded material was placed in an oven at 550 ° C for 2 h using a galvanized iron reactor (without air) and sieved (120 mesh). Prepared carbon was placed in 2 molar sulfuric acid for 2 h at laboratory temperature. Then, pH of the solution was adjusted by 1 molar sodium hydroxide in the range of 6-6.5 and the sample was put in the oven at 105 ° C for 24 hours to dry. After that the dried sample was placed in a furnace at 550 °C for 2 hours and then milled. Materials were separated by standard 120 sieve with ASTM mesh of 80-120.

**2. 1. 3. GAC/NZVI Preparation**      To coat the prepared activated carbon with iron nanoparticles, firstly, 100 ml of 0.07 M $FeSO_4.7H_2O$ solution was prepared in mixture of water and ethanol with a certain  volume ratio (ethanol/water = 3/7), then 4 g of activated carbon and 0.5 g of starch were added. On vigorous magnetic shaking, 50 ml of $NaBH_4$ (reductive solution) was gradually added (2 ml/min) for 30 min. Next, the prepared GAC/NZVI was filtered and washed three times with ethanol and deionized water. The filtered materials were dried at 70 °C in vacuum oven for 24 h. In all steps, $N_2$ gas continuously flowed into the solution to maintain the inert atmosphere.

**2. 1. 4. Characterization of Adsorbents**      To determine the specific surface characteristics of activated carbon (GAC), zero valent iron nanoparticles (NZVI), and coated activated carbon nanoparticles by zero valent iron nanoparticles (GAC/NZVI), FESEM was used. FTIR was used to identify the functional groups, EDXA was also applied to determine the constituent elements, and BET analysis was used to study the porosity.

**2. 1. 5. pHzpc Determination**      In order to determine pH of zero point of charge ($pH_{ZPC}$) as an important characteristic of the adsorbents, 180 ml of sodium chloride solution (0.01 molar) was poured  in 650 ml-Erlenmeyer flask (30 ml per flask) and the pH was

adjusted in the range of 2-12. Then, 0.5 g of the carbon sample was added to each flask. The flasks were placed on a shaker at a speed of 120 rpm for 24 h. After that the samples were filtered and the final pH of each sample was measured. $pH_{ZPC}$ was determined by plotting the initial pH values versus final pH values [30].

**2. 2. Methods**      Experiments were performed in batch mode. The effect of different variables on nitrate removal efficiency was investigated: activated carbon and activated carbon coated with iron particles dosage (0.2 – l g) in 100 ml, nitrate concentration (25-150 mg / l) and pH (2-10). The speed of the shaker was 150 rpm in all experiments and the temperature was 25 $^0$C. The concentration of nitrate was measured by spectrophotometry (using a UV spectrometer at 220 nm) and in most cases, control samples were used to reduce the effect of the interventional agents. To ensure results, at least every test was repeated twice, and the average results were reported. Equation (1) was used to determine the removal (uptake) efficiency.

$$Uptake(\%) = \frac{(C_0 - C_e)}{C_0} \times 100 \tag{1}$$

in which, $C_0$ and $C_e$ indicate the initial concentration (mg/L), and equilibrium concentration (mg/L), respectively.

In the next step, the adsorption capacity was determined using equilibrium time of the solution according to Equation (2).

$$q_e(mg/g) = (C_0 - C_e)V/m \tag{2}$$

where, $q_e$ is the amount of adsorbed nitrate per adsorbent (mg/g), $C_0$ is initial concentration of nitrate (mg/L), $C_e$ is equilibrium concentration of nitrate (mg/L), V is the volume of liquid in the flask (L) and M is adsorbent mass (g).

**2. 2. 1. Isotherm Models**      To evaluate isotherm models, the constant amount of adsorbent 0.6 g/100 ml was mixed with various concentrations of nitrate at 25-150 mg/l at pH 4, for 72 h. Adsorption equilibrium was analyzed using Langmuir and Freundlich isotherm models. The Langmuir linear model is expressed as Equation (3):

$$\frac{C_e}{q_e} = \frac{1}{bq_m} + \frac{1}{q_m} \times C_e \tag{3}$$

in which $q_m$ is adsorption capacity of a single layer (mg/g), b is constant of Langmuir (L/mg), $C_e$ is the concentration of dissolved nitrate at equilibrium (mg/l), and $q_e$ is nitrate adsorbed on the adsorbent (mg/g). As already mentioned, in this equation, $q_m$ and b are maximum adsorption capacity and Langmuir constant, respectively, which are obtained from the plot of $1/q_e$ versus $1/C_e$.

In the Langmuir model, the dimensionless factor $R_L$ (Equation (4)), called equilibrium parameter, shows the desirability of the adsorption process. The adsorption process can be appropriate ($0 < R_L < 1$), inappropriate ($1 < R_L$), linear ($R_L = 1$) and irreversible ($R_L = 0$)[31, 32].

$$R_L = \frac{1}{1+K_1C_0} \tag{4}$$

The linear model of Freundlich isotherm is expressed as Equation (5).

$$log q_e = log K_f + \frac{1}{n} log C_{fe} \tag{5}$$

where, $k_f$ and n are Freundlich constants dependent on the capacity and adsorption intensity, obtained from the log $q_e$ diagrams versus log $c_e$. In this equation $q_e$ is the amount of nitrate adsorbed at equilibrium (mg/g), $C_e$ is the concentration of nitrate adsorbed at equilibrium time (mg/g) and $q_m$ is the maximum adsorption capacity (mg/g). The value of $1/n$ in Freundlich equation describes the type of Freundlich isotherm. If the value is $1/n = 0$ the adsorption reaction is irreversible, if $0 < 1/n < 1$ and $1 < 1/n$, the adsorptions are desirable and undesirable, respectively [31-33].

# 3. RESULTS AND DISCUSSION

## 3. 1. Adsorbent Characteristics
### 3. 1. 1. Determination of Adsorbent Surface Morphology with SEM      In Figure 1, electron microscopic images (FESEM) depicts the morphology of activated carbon, nanoparticles, and activated carbon coated with iron nanoparticles prior to the adsorption process. Activated carbon surface is roughly heterogeneous, the surface of iron nanoparticles is in granular form with heterogeneous sizes and shapes, and the activated carbon surface coated with nanoparticles of iron has a granular and heterogeneous structure due to the stabilization of nanoparticles on activated carbon. The images show that iron nanoparticles are well stabilized on activated carbon, which is completely different from the original activated carbon image. In other studies, the morphology of activated carbon surface is also changes by stabilization of nanoparticles [30, 34].

Figure 1, shows the surface of activated carbon and activated carbon coated with nanoparticles after the adsorption. After the adsorption process, the porosity of adsorbent surfaces decreased, that is in  accordance with other works [30, 34].

### 3. 1. 2. EDXA Analysis      Figure 2 shows the EDXA analysis of the elements in the adsorbents. In activated carbon driven from grape wood, weight percentage of carbon is about 98.4% (the main ingredient) and the weight percentage of other elements is negligible (O = 1% and N = 0.57%). Meanwhile, in the GAC/NZVI catalyst, 49.8% of the weight was carbon, 30.5% was iron, 12.2% nitrogen and 7.4% oxygen. The results of the

analysis showed a high content of iron and carbon in the GAC/ NZVI.

**3. 1. 3. Determination of Catalyst Surface Functional Groups by FTIR**      The results of the FTIR analysis of GCA, NZVI and GAC/NZVI in the range of 600-4000 cm$^{-1}$ are shown in Figure 3. Adsorption peaks in the range of 3200-3600 cm$^{-1}$ are assigned to fluctuation bands of stretching O-H bond in the carboxylic acid functional groups and adsorbed water after chemical activation [35]. Adsorption peaks in the range of 1000-1800 cm$^{-1}$ are likely related to oxygen-containing groups such as C = O and C-O-R structures. C = O bond exists in compounds such as amides, esters, carboxylic acids, and C-O-R presents in compounds such as aryl and alkyl ethers and phenols, and alcohols and carbohydrates, etc [35]. In addition, adsorbed peaks in the range of 600-700 cm$^{-1}$ are corresponded to the C-H functional groups present in organic compounds [34].

**3. 1. 4. Analysis Surface Characteristics of GAC and GAC/NZVI** The values of specific surface area and pore volume of GAC, NZVI and GAC/NZVI are shown in Table 1.
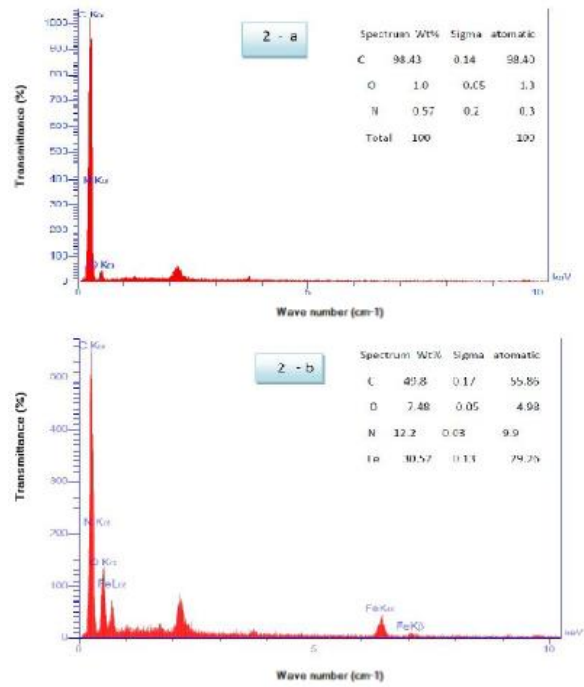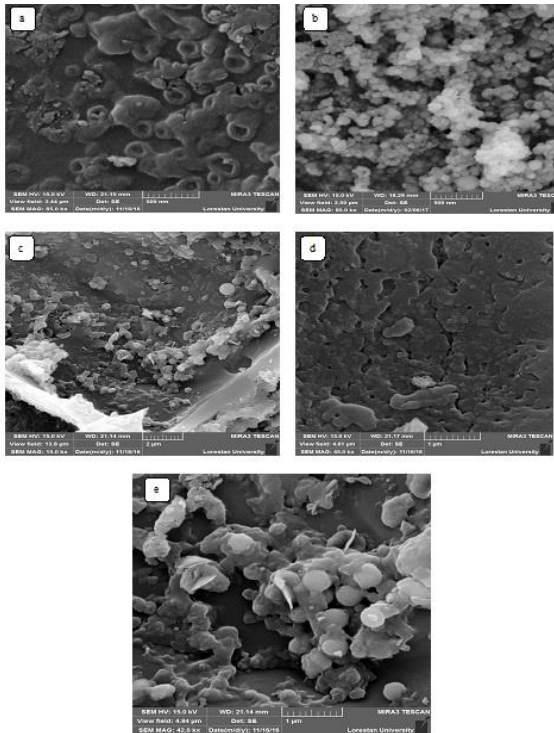


**Figure 1.** FESEM images of the adsorbents, a, b and c, respectively, represent the activated carbon made by grape wood, the iron nanoparticles, and the activated carbon coated with the iron nanoparticles before adsorption, and the images d and e, respectively, the activated carbon made by grape wood and coated activated carbon after adsorption
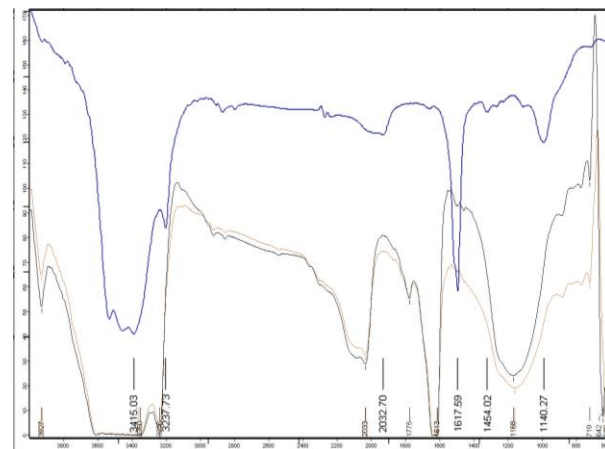


**Figure 2.** The EDXA analysis results for (a) GAC and (b) GAC/NZVI)



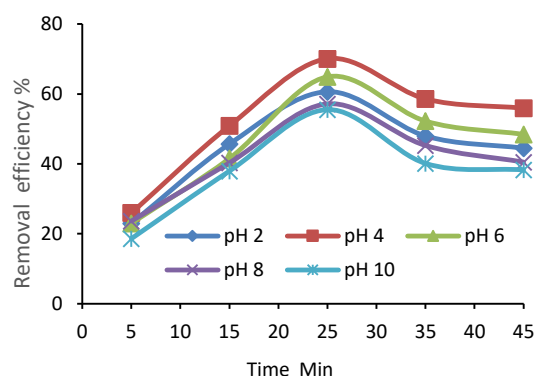**Figure 3.** FTIR adsorption spectra of GAC( ),NZVI(   )and GAC / NZVI(—)

The specific surface area of GAC, NZVI and GAC/NZVI was 1169, 1454 and 1050 m$^2$/g, respectively, and BET constant was 715, 784 and 813, and the mean diameter of their pores was 3.3, 1.2 and 2.5 nm, respectively. Reducing the pore diameter in coated carbon reflects the presence of iron nanoparticles in activated carbon pores. The change in the diameter and the reduction of carbon adsorbent pores with coating nanoparticles was also seen in other studies [34].

**TABLE 1.** BET analysis results for GAC, NZVI and GAC/NZVI'

| Factors | units | GAC | NZVI | GAC/NZVI |
|---------|-------|-----|------|----------|
| **BET** | $m^2/g$ | 1169 | 1454 | 1050 |
| Total pore volume = 0.982 $P/P_0$ | $cm^3/g$ | 0.3384 | 0.2598 | 0.2837 |
| **BET** constant | - | 715 | 784 | 813 |
| Average pore diameter | nm | 3.3 | 1.2 | 2.5 |

**3. 2. The Effect of Initial pH, Contact Time** One of the influential factors affecting the adsorption process is pH of the solution, which affects the adsorbent surface load, ionization, the property of the adsorbing structure, the functional groups in the active sites, as well as the solubility [36]. In Figure 4, the effect of pH on nitrate removal is shown in the presence of GAC adsorbent. The maximum nitrate adsorption efficiency was 70% at pH 4, and after 25 min, the process of desorption began while activated carbon $pH_{zpc}$ was 4.6. At pH lower than 4.6, due to protonation or positive adsorption surface due to the high concentration of $H^+$, nitrates were adsorbed electrostatically and increased the removal efficiency. On the other hand, a large reduction of pH to about 2 caused the intervention of rival anions such as $SO_4^{-2}$ and $Cl^-$, thus reducing the removal efficiency. At higher pH (buffer), much higher than 4.6, because of the negative surface of the adsorbent, in the presence of high concentrations of $OH^-$ the amount of nitrate adsorption decreased due to electrostatic repulsion as the same results were reported by other works [37, 38].

In Figure 5, the effect of pH on the removal of nitrate by NZVI is shown. The maximum nitrate uptake was 90.3% at pH 2.
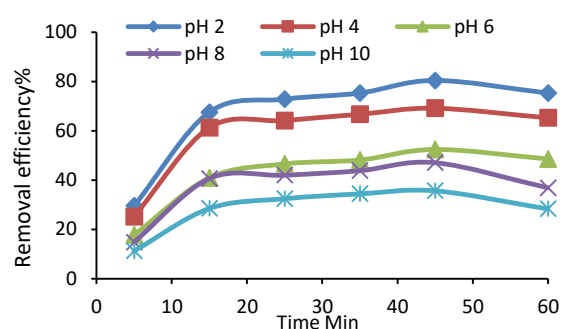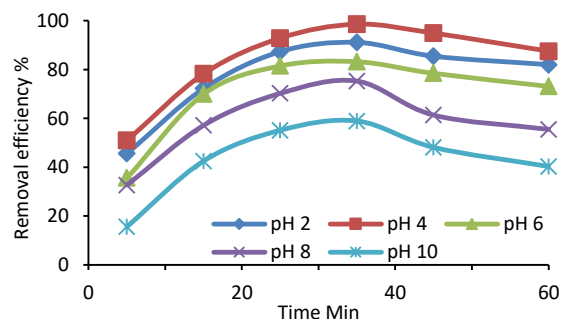


**Figure 5.** The effect of pH on nitrate removal efficiency in the presence of NZVI (concentration of nitrate 150 mg/l, contact time of 5-45 min and NZVI 0.6 g)

The reason is due to the presence of high concentration of proton at low pH values and thus the reduction of nitrate according to Reactions (6) and (7) by iron nanoparticles occurs as other researchers reported the same findings [3, 22].

$$NO^{3-} + Fe_0 + 2H^+ \rightarrow Fe_2^{2+} + NO^{2-} + H_2O \qquad (6)$$

$$NO^{3-} + 4H_2 + 2H^+ \rightarrow NH_4^+ + 3H_2O \qquad (7)$$
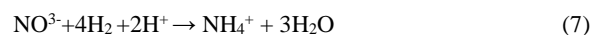
It should be noted that at higher pH levels and in the presence of iron nanoparticles, nitrate was removed partially due to the positive charge at the surface of the nanoparticles. After 45 min, the desorption phenomenon occurred.

Figure 6 depicts the effect of pH on the process of nitrate removal by GAC/NZVI. The maximum nitrate removal efficiency was 98.5% at pH 4. After 35 min, the process of desorption began due to the combined effect of activated carbon and iron nanoparticles. The reason for its high efficiency was probably due to an increase in the positive charge level of activated carbon coated with iron nanoparticles, which was able to adsorb more nitrate than before. However, according to the Reactions (6) and (7), nitrate reduction process was effective.



**Figure 4.** The effect of pH on nitrate removal efficiency in the presence of GAC (concentration of nitrate 150 mg/l, contact time of 5-45 min and GAC 0.6 g)



**Figure 6.** The effect of pH on nitrate removal efficiency in the presence of GAC/NZVI (concentration of nitrate 150 mg/l, contact time of 5-45 min and GAC/NZVI 0.6 g)

In fact, carbon coating with iron nanoparticles, increased the efficiency of nitrate removal and moreover, delayed the process of desorption. Other studies have found similar results [28, 37, 39].

### 3. 3. The Effect of Nitrate Concentration

**3. 3. 1. The Effect of Initial Concentration of Nitrate on the Removal Efficiency by GAC**     The effect of the initial concentration of nitrate on its removal efficiency in the presence of GAC is shown in Figure 7. As shown, by increasing nitrate concentration, the removal efficiency decreased. Increasing the concentration of pollutants in solution and increasing the amount of their adsorption rate, reduces the active surface of adsorbent and neutralizes more active groups on the surface. Therefore, the removal efficiency is reduced, other researchers obtained similar results [29, 40].

**3. 3. 2. The Effect of Initial Concentration of Nitrate on the Removal Efficiency by NZVI**     The effect of the initial concentration of nitrate on its removal efficiency by NZVI is shown in Figure 8. By increasing the nitrate concentration the removal efficiency decreased. By increasing the concentrations of pollutants active surface sites on the adsorbent decreases consequently neutralizes and deactivates activated groups [23, 28].

According to the results as the maximum removal efficiency occurred at 150 mg/l of nitrate concentration thus, 150 mg/l was used for the next steps of the study.

**3. 3. 3. The Effect of Initial Concentration of Nitrate on the Removal Efficiency by GAC/NZVI** The effect of the initial concentration of nitrate on its removal efficiency in the presence of GAC/NZVI is shown in Figure 9. By increasing the nitrate concentration, the removal efficiency decreased, but compared to the two previous ones, this reduction was not significant.
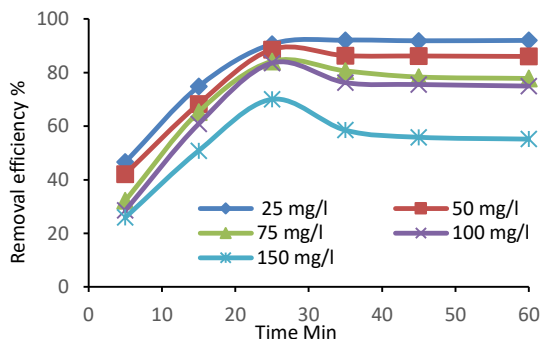
Even at concentration of 150 mg/l after 35 min, the removal efficiency was 98%. Increasing of nitrate concentration and its adsorption, decreases the active sites on the adsorbent, neutralizes the active groups of the surface and increases the negative charge of the adsorbent, thus, the removal efficiency is reduced [27, 28]. Due to the optimum removal efficiency achieved at maximum concentration, 150 mg/l of nitrate concentration was used for the next steps of the study.

**3. 3. 4. The Effect of Dosage of NZVI, GAC and GAC/NZVI on Nitrate Removal**     The effect of the adsorbent dosage on the removal of nitrate is shown in Figures 10-12. By increasing the amount of NZVI from 0.2 to 1 g, the removal efficiency increased from 59.84 to 80.47%. By increasing GAC from 0.2 to 1 g, the removal efficiency increased from 63.8 to 82.85% and by increasing the GAC/NZVI from 0.2 to 1 g, adsorption efficiency increased from 82.22 to 97.76%. According to the results, by increasing the adsorbent dosage, contact surface and active adsorption sites increased, thus more nitrate adsorption happened.
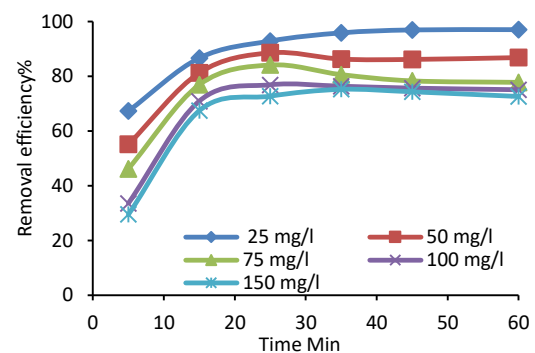


**Figure 8.** The effect of initial nitrate concentration on removal efficiency in the presence of NZVI (concentration of nitrate 25-150 mg/l, contact time of 5-45 min, pH 2 and NZVI 0.6 g)
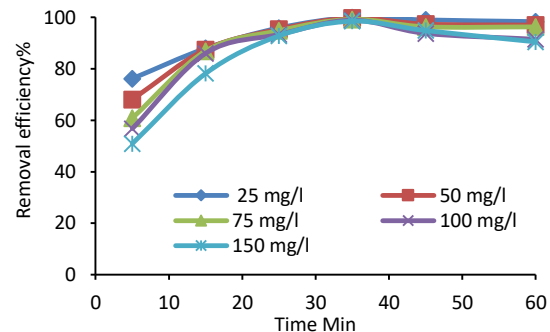


**Figure 7.** The effect of initial nitrate concentration on removal efficiency in the presence of GAC (concentration of nitrate 25-150 mg/l, contact time of 5-45 min, pH 4 and GAC 0.6 g)



**Figure 9.** The effect of initial nitrate concentration on removal efficiency in the presence of GAC/NZVI (concentration of nitrate 25-150 mg/l, contact time of 5-45 min, pH 4 and GAC/NZVI 0.6 g)
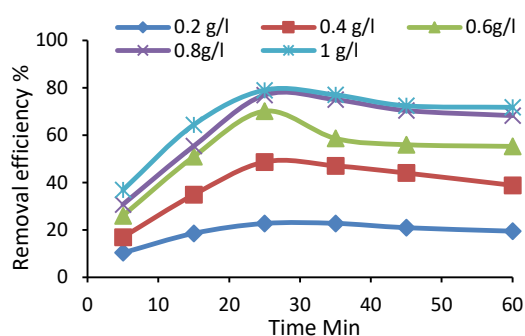
**Figure 10.** The effect of GAC concentration on nitrate removal efficiency (concentration of nitrate 150 mg/l, contact time of 5-45 min, pH 4)
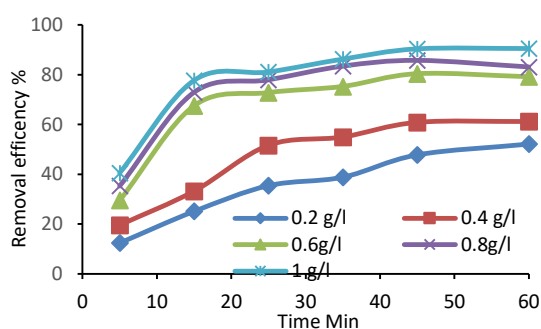


**Figure 11.** The effect of NZVI concentration on nitrate removal efficiency (concentration of nitrate 150 mg/l, contact time of 5-45 min, pH 2)
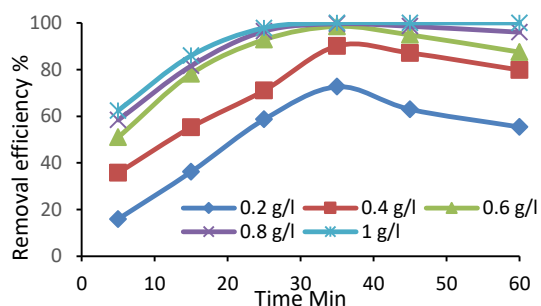


**Figure 12.** The effect of GAC/NZVI concentration on nitrate removal efficiency (concentration of nitrate 150 mg/l, contact time of 5-45 min, pH 2)

Similar finding has been reported by other researchers [41, 42].

**3. 4. Adsorption Isotherm Models**        Adsorption isotherms are one of the most influential factors in designing the adsorption systems. In fact, the adsorption isotherm explains the interactions between adsorbent and adsorbate. Therefore, in optimizing the consumption of adsorbent and determining the amount of adsorbent capacity it plays an important role [43].

The results of the linear Langmuir model (single layer) and Freundlich (multi-layer) are presented in Table 2 for all types of adsorbents. According to the results, the performance of NZVI and GAC/NZVI was more consistent with the Langmuir model indicating a nearly uniform distribution of the adsorption reaction energy [43, 44] and the GAC function was more consistent with the Freundlich model, indicating a non-uniform distribution of the adsorption reaction energy at the adsorbent surface [44]. Based on Langmuir model, the maximum adsorption capacities for GAC, NZVI and GAC/NZVI were 37.51, 36.25 and 55.82 (mg/g), respectively.

**3. 5. Nitrate Adsorption Kinetics by GAC, NZVI and GAC / NZVI**       The two important kinetic models widely used for the adsorption process are first and second order kinetic models. When the surface adsorption occurs by penetration through a layer, the kinetic model is the first order. If the chemical adsorption be the slowdown phase of reaction rate and control surface adsorption process, the kinetic model will be second order[45].

In Table 3, the results of the kinetic models analysis of nitrate adsorption using GAC, GAC/NZVI and NZVI are shown. The comparison of the correlation among kinetics showed that adsorption rate was mostly consistent with the pseudo second-order, which shows the effect of two factors (surface adsorption and chemical adsorption) on the reaction rate and is dominated by chemical adsorption [43]. The reduction of nitrate with iron nanoparticles is also a chemical process.

**TABLE 2.** Nitrate adsorption isotherms parameters for GAC, NZVI and GAC / NZVI

| Models and Isotherms | Langmuir | | | Freundlich | | |
|---|---|---|---|---|---|---|
| Absorbent | $R^2$ | b l/mg | $q_m$ mg/g | $R^2$ | $K_f$ l/mg | n |
| GAC | 0.938 | 0.028 | 37.51 | 0.954 | 3.36 | 1.3 |
| NZVI | 0.966 | 0.961 | 36.25 | 0.924 | 1.877 | 0.85 |
| GAC/NZVI | 0.965 | 0.785 | 55.82 | 0.966 | 2.024 | 0.998 |

**TABLE 3.** Kinetics of nitrate adsorption by GAC and GAC/NZVI at pH 4, and by NZVI at pH 2, and nitrate concentration of 150 mg/l

| process | pseudo second-order $t/q_t =(1/k_1q_e^2)+t/q_e$ | | | pseudo first-order $\log(q_e-q_t)=\log q_e-k_1t/2.303$ | | |
|---|---|---|---|---|---|---|
| | $q_e$ mg/g | $k_2$ g/mg.min | $R^2$ | $q_e$ mg/g | $k_1$ 1/min | $R^2$ |
| GAC | 32.94 | 0.0012 | 0.9411 | 16.32 | 0.028 | 0.798 |
| NZVI | 50.25 | 0.005 | 0.9582 | 32.14 | 0.016 | 0.811 |
| GAC/NZVI | 76.56 | 0.0047 | 0.9744 | 45.24 | 0.019 | 0.755 |

## 4. CONCLUSIONS

The aim of this study was to evaluate the use of activated carbon produced from grape wood coated by iron nanoparticles as a cheap adsorbent for nitrate removal from aqueous solutions. The results obtained from this study are as follow:

1. The nitrate adsorption rate is highly dependent on pH and the highest adsorption occurs at pH below the pH.zpc. As the pH was very acidic (less than 2), the removal efficiency was reduced.
2. By increasing the initial concentration of nitrate, the removal efficiency decreased but the amount of nitrate removed per mass unit of adsorbent increased.
3. The adsorption efficiency increased by increasing the adsorbents concentration in all cases.
4. The nitrate adsorption by GAC was more consistent with the Freundlich model, and the nitrate adsorption by GAC/NZVI and NZVI was more consistent with Langmuir model.
5. The nitrate adsorption was mainly consistent with the pseudo second-order kinetic model, indicating that the absorption was carried out on heterogeneous sites on the adsorbents.

## 5. ACKNOWLEDGMENT

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# Nitrate Removal from Aqueous Solutions Using Granular Activated Carbon Modified with Iron Nanoparticles

B. Kamarehie[a], E. Aghaali[b], SA. Musavi[c], SY. Hashemi[d], A. Jafari[a]

[a] Nutrition Health Research Center, Department of Environment Health, School of Health and Nutrition, Lorestan University of Medical Sciences, Khorramabad, Iran,
[b] Department of Environment Health, Lorestan University of Medical Sciences, Khorramabad, Iran
[c] Department of Environment Health, Faculty of Health, Kermanshah University of  Medical Sciences, Kermanshah, Iran
[d] Department of Environment Health, Faculty of Health,, Tehran University of Medical Sciences, School of Health, Tehran, Iran

| P A P E R   I N F O | چکیده |
|---|---|
| | آلودگی منابع آب به نیترات و سرعت رو به رشد افزایش غلظت نیترات در منابع مذکور، سلامت انسان و محیط زیست را به مخاطره انداخته است و بررسی راهکارهای کاهش آن از منابع آب اهمیت بسزایی دارد. این مطالعه با هدف بررسی امکان استفاده  از کربن فعال گرانوله حاصل از چوب انگور پوشش داده شده با نانو ذرات آهن برای حذف نیترات از محلول های آبی انجام شد.  نتایج نشان داد بیش از 99 درصد از نیترات با استفاده از GAC/NZVI از محلول حذف شد، و  فرایند  جذب نیترات با GAC از ایزوترم فروندلیچ (R$^2$= 0.95) و  با  NZVI و GAC/NZVI از ایزوترم لانگمویر (R$^2$=0.96) پیروی می کرد. همچنین مطالعه کنتیکی هر سه جاذب در جذب نیترات  بیشترین هم بستگی را  با معادله درجه دوم کاذب نشان داد. با توجه  به نتایج حاصل از این مطالعه می توان اظهار نمود که کربن فعال حاصل از چوب انگور با پوشش نانو ذرات آهن یک جاذب نسبتا ارزان قیمت و مناسب برای جذب نیترات از آب می باشد. |