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Electrochemical process for removing nitrate from drinking water by Taguchi model

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ABSTRACT

The use of nitrogenous fertilizers, detergents, the food industry, the power industry, and nuclear fuels are all man-made causes of nitrate pollution. High nitrate levels in drinking water (>50 mg/L) cause blue baby syndrome (methemoglobinemia), particularly in children, as well as the development of carcinogenic nitrosamines. The goal of this applied-analytical research is to see how well a batch electrochemical (E) reactor with monopolar electrode mode can remove nitrate from urban drinking water. The effects of several operational factors on nitrate removal were investigated, including current density, electrode material, pH, and time. The efficacy of nitrate removal is investigated under various working conditions including current density (1–8 mA/cm^2), electrode material (aluminum, copper, iron, steel, and zinc), pH (6–8), and time (5–40 min). The amount of nitrate in the body is measured using a process outlined in standard standards (4500-NO_3-B). At comparable experimental circumstances, As–As anode–cathode electrodes generate the lowest nitrate removal (0.1%), whereas Zn–Cu anode–cathode electrodes provide the maximum nitrate removal (100%). Batch tests revealed that employing zinc–copper as the anode–cathode electrode configuration resulted in the most nitrate elimination. The increase in current density from 1 to 8 mA/cm^2 at the optimal electrode and pH resulted in a 62%–100% improvement in nitrate removal. The increase in duration from 5 to 40 min at the optimal electrode and pH resulted in a 33%–100% increase in nitrate removal. The researchers discovered that increasing current density, electrolysis duration, and pH improved nitrate removal efficiency. As a result of batch tests, the electrochemical reactor seems to be effective in removing nitrate from drinking water and might be regarded a viable method for treating nitrate-polluted water. It was suggested that a bio- electrochemical reactor be investigated.

Keywords: Blue baby syndrome; Electrochemical batch reactor; Nitrate removal; Urban drinking water; Zinc–copper electrodes

1. Introduction

According to recent estimates, nitrate poisoning of water resources, particularly ground water, is becoming one of the most pressing worldwide environmental issues owing to its high solubility [1]. According to a study of public water supplies in the United States, the proportion of public water system (PWS) that exceed the maximum concentration limit (MCL) of nitrate drinking water (10 mg/L as NO_3–N) is projected to have increased from 0.28% to 0.42% between 1994 and 2009. As a result, the use of treatment systems necessitates adherence to stringent nitrate rules as a persistent pollutant [2,3]. In 2012, the mean nitrate drinking water content in 108 municipalities in Spain was 3.5 mg/L NO_3 (limitation: 0.4–66.8) [4]. In India, the maximum nitrate content in drinking water is reported to be 100 mg/L NO_3 in certain places [5]. The concentration of nitrate in drinking water in seven sites (about 8%) is projected to be higher

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than Iran's maximum acceptable limit. The provinces of Alighardashi and Mehrani [6] have the highest nitrate drinking water concentrations. Concerns about nitrate levels have been raised across the globe as a cause of declining surface and groundwater quality in the past four decades [7]. The rise in nitrate levels in groundwater has been linked mostly to the overuse of nitrogenous fertilizers, particularly nitrate-N, as well as animal waste, septic tanks, municipal sewage treatment systems, and decaying plant detritus [6]. Non-point pollution (nitrogen-rich fertilizers) is a significant source of nitrate in the environment [8]. The major source of eutrophication is the entrance of nitrogen into surface runoff as a result of human activities, which results in decreased water river quality and irreversible ecological threats [9,10]. Nitrate-contaminated water above the permissible drinking water limit causes thyroid problems, methemoglobinemia (also known as "baby blue syndrome"), which is a problem with transferring oxygen to the baby's body and has a strong link to excess nitrate levels. Nitrate-contaminated water is also a source of carcinogens (colorectal cancer incidence is estimated to be 6,500 cases of nitrate-attributable cancers), and the drinking water standard has been set as 10 mg/L as NO_3–N [8,11–13]. Because of the harmful effects of this contaminant, it is vital to limit its concentration in drinking water sources. Because nitrate in water is soluble and stable, traditional water treatment processes like chlorination, coagulation, and filtration are ineffective at eliminating it, necessitating the use of sophisticated treatment technologies. Ion exchange, biological denitrification, chemical denitrification, reverse osmosis, adsorption, and electrodialysis are some of the technologies that have been used to remove nitrate from drinking water. In terms of nitrate destiny in water treatment, separation-based and removal-based approaches are the most used [14]. Membrane processes, on the other hand, have a number of drawbacks, including high installation and maintenance costs, influent water quality, such as salinity, and brine formation [15]. The cost of electrodialysis is considerable [15]. Reverse osmosis has a number of disadvantages, including high installation and maintenance costs, the requirement for pre-treatment, poor water efficiency in low-pressure applications, membrane monitoring, and continual maintenance. An additional approach for removing nitrate from ground water is electrochemical removal [16]. Electrochemical technique has a number of benefits over traditional approaches, including ease of reactor setup, elimination of the need for chemical post-treatment, performance, compatibility, safety, cost-effectiveness, and facility management [17]. This method removes nitrates selectively. Cell organization, coexisting ions, electrode materials, and pH all influence the products generated during electrolysis, such as nitrogen (N_2), nitrous oxide (N_2O), nitrogen oxide (NO), ammonium (NH_4^+), and nitrogen dioxide (NO_2) [18]. Guo et al. [19] reported electrochemical and electrocoagulation removal of nitrate and phosphate from municipal wastewater treatment plant effluent using an aluminium or iron electrode with an 8 mA/cm^2 current density. Su et al. [20] investigated the electro-catalytic removal of nitrate using copper/stainless steel (Cu/SS) and palladium-copper/stainless steel (Pd–Cu/SS) electrodes and a sodium perchlorate electrolyte. Moradi and Ashrafizadeh [21] reported electrocoagulation–flotation removal of nitrate from tap water using a range of electrodes. The major goal of this research is to look into the impact of the batch electrochemical reactor's principal operational parameters on its effectiveness in treating nitrate-contaminated urbane drinking water. Current density, electrode material, pH, and time were among the criteria considered.

2. Material and methods

2.1. Materials

2.1.1. Chemical materials

Merck Co. provided sulfuric acid, potassium nitrate, and sodium hydroxide (Germany). pH was adjusted using sulphuric acid and sodium hydroxide (1 N).

2.1.2. Preparation of electrodes

After cleaning with distilled water, the weight of the electrode is determined. The electrode is cleaned with detergent and tap water before use. The electrode is cleaned and dried before being immersed in water in the reactor [22].

2.1.3. Experimental set-up

The batch electrochemical reactor is a 360 mL glass vessel (10 cm × 6 cm × 6 cm) (Fig. 1). Various materials of aluminium (Al), copper (Cu), iron (Fe), steel (As), and zinc (Zn) are used as anode and cathode electrodes (Pars, Iran). The area of each electrode is 36 cm^2 (9 cm × 4 cm × 0.1 cm). The spacing between the electrodes is set at 2 cm. The maximum electrical power of the AC electrical supply is 60 W (Iran Jahesh, Iran). To determine the influence of electrolysis on the nitrate removal process, samples are electrolyzed at various current densities (1–8 mA/cm^2), electrode materials (Al, Cu, Fe, As, and Zn), pH (about 6–8), and periods (5–40 min). For homogenous mixing of water samples, a magnetic stirrer (AiKa, Germany)

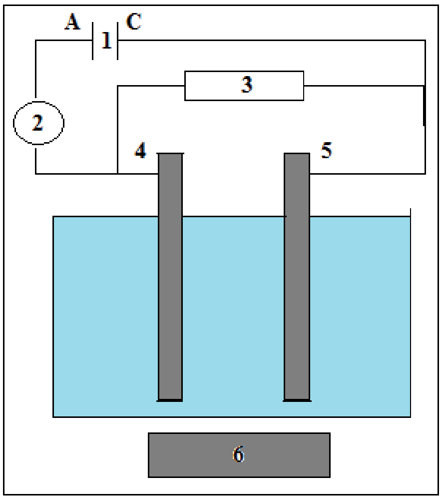

Fig. 1. The batch electrochemical reactor. (1) Power supply, (2) Current density (1–8 mA/cm^2), (3) Voltage volume (1–60 V), (4) Cathode electrode, (5) Anode electrode, and (6) Magnetic stirrer.

is utilized (Table 2). 200 mL of sample water is placed into the reactor for each test. All tests are carried out at a constant temperature of 20°C in the laboratory.

2.1.4. Preparation of water sample

Nitrate-contaminated water samples for electrochemical tests were collected from an urbane distribution system near a laboratory of Tehran Medical Sciences Branch in Tehran, Iran. The samples are examined for the most important physico-chemical properties. Table 1 shows the average values of various water parameters.

2.2. Methods

2.2.1. Analytical methods

All tests are run three times and the average data values are presented. After electrochemical testing, the water samples are analyzed for nitrate, oxidation–reduction potential (ORP), pH, and temperature using a spectrophotometer (Unico UV-2100, Germany), ORP-meter (CG, Malesia), and pH-meter (Hack, America), respectively. Nitrate is measured at 220 and 275 nm using the approach described in standard method 4500-NO3-B [23]. Eq. (1) [24] is used to compute the % nitrate removal:

$$R(\%) = \frac{C_0 - C}{C_0} \tag{1}$$

where the percentage of nitrate removal (*R*, percentage) and the nitrate value before and after treatment (C_0 and C, mg/L) expressed.

Table 1
Main physico-chemical characteristics of nitrate-contaminated urbane water

Parameter	Value
Calcium, mg/L as $CaCO_3$	55
Dissolved oxygen, mg/L	8
ORP, mV	279
pH	7.12
Sulfate, mg/L	42.8
Temperature, °C	16
Total alkalinity, mg/L as $CaCO_3$	52

According to studies, two kinetic models, including first-order, and second-order, are used for fitting the experimental data and obtain the best results. The comparison and assessment of the correlation coefficient (R^2) show the best accordance with kinetic model. In this research, the following kinetic models are used to investigate the behavior and knowledge of the reaction rate. Kinetics reaction models are computed based on Eqs. (2) and (3) [25]:

$$\ln C_t = \ln C_{t0} - K_1 t \tag{2}$$

$$\frac{1}{C_t} = \frac{K_2 t + 1}{C_{t0}} \tag{3}$$

where C_0 and C_t are the concentration of nitrate at the beginning and after time *t* of the reaction, respectively. K_1 and K_2 are the first, and second order reaction constants, respectively. Values of K_1 and K_2 can be computed from the slope of the plots $\ln C_t$ vs. *t*, and $1/C_t$ vs. *t*, respectively.

Electrodes are rinsed with distilled water after conducting all tests. Table 2 indicates the batch operational conditions of electrochemical experiments.

3. Experimental observations

The findings of this research are shown in the following table. The effects of current density, electrode material, pH, and time on the efficacy of an electrochemical reactor in removal nitrate from nitrate-contaminated urbane drinking water are studied.

3.1. Effect of electrode materials

At the experimental circumstances listed in Table 2, Fig. 2 depicts the impact of anode and cathode electrode materials on nitrate removal. At comparable experimental circumstances, As–As as anode–cathode electrodes generate the lowest nitrate removal (0.1%), whereas Zn–Cu as anode–cathode electrodes create the maximum nitrate removal (100%), as shown in Fig. 2 (Table 2).

3.2. Effect of water pH

At the experimental conditions listed in Table 2, electrochemical tests are carried out with initial pH values in the range of 6 to 8. The results are shown in Fig. 3.

Table 2
Batch operational conditions of electrochemical experiments

Run	Experiment	Batch operational conditions			
		Electrodes material (anode–cathode)	pH	Current density (mA/cm^2)	Time (min)
1[a]	Effect of electrodes material	AS, Al, Cu, Fe, Zn	Natural	8	40
2[b]	Effect of water pH	Zn–Cu	6–8	8	40
3[b]	Effect of current density	Zn–Cu	8	1–8	40

[a] The first-run was performed under constant conditions of variables.

[b] The second and third-runs were performed based on the results after pre-test (run 1) in variable conditions.

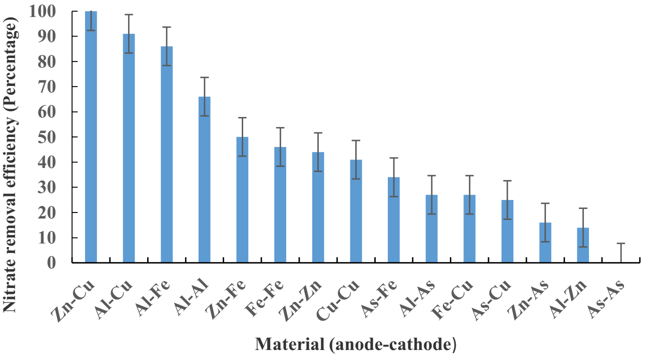

Fig. 2. The impact of electrodes material on the nitrate removal in the batch electrochemical reactor (experimental conditions: 20°C; pH: 8; reaction time: 40 min; current density: 8 mA/cm^2).

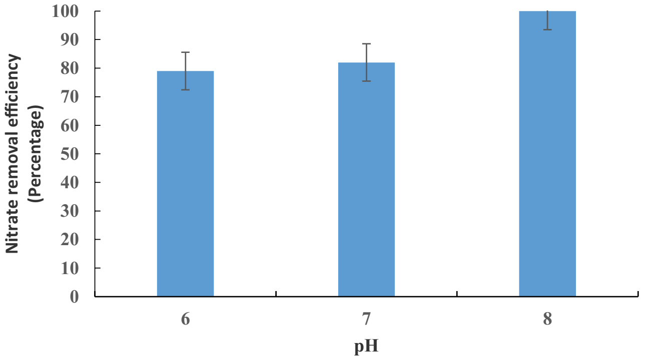

Fig. 3. The impact of water pH on the nitrate removal in the batch electrochemical reactor (experimental conditions: 20°C; pH: 6–8; reaction time: 40 min; current density: 8 mA/cm^2).

When the pH of the Zn–Cu anode–cathode electrodes is adjusted from 6 to 8, the mean nitrate removal rises from 79% to 100%.

3.3. Effect of current density

At the experimental settings listed in Table 2, electrochemical studies are carried out at current density levels ranging from 1 to 8 mA/cm^2. As the current density and duration rise, the effectiveness of nitrate removal improves. Fig. 4 shows the final findings. When the current density of the Zn–Cu anode–cathode electrodes is increased from 1 to 8 mA/cm^2, the mean nitrate removal rises from 62% to 100%.

3.4. Anode weight loss

The value of anode weight loss in the electrochemical reactor is shown in Fig. 5 for the experimental circumstances listed in Table 2. The anode consumed mass rises with increasing current density, as seen in Fig. 5. When the current density of the Zn–Cu anode–cathode electrodes is increased from 1 to 8 mA/cm^2, the mean anode weight loss rises from 3 to 23 mg.

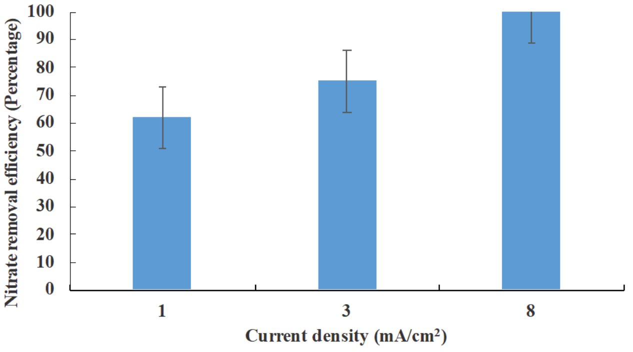

Fig. 4. The impact of current densities on the nitrate removal in the batch electrochemical reactor (experimental conditions: 20°C; pH: 8; reaction time: 40 min; current density: 1–8 mA/cm^2).

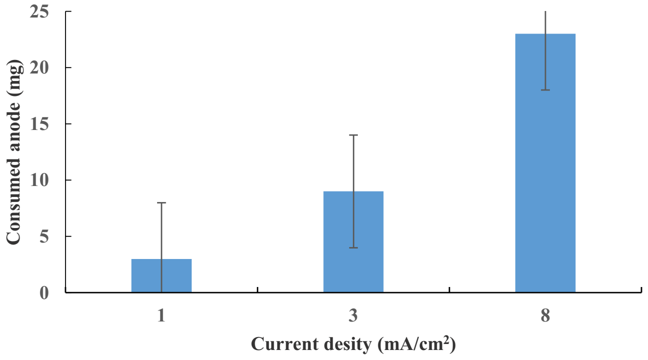

Fig. 5. The anode weight lost in the batch electrochemical reactor as a function of current densities (experimental conditions: 20°C; pH: 8; reaction time: 40 min; current density: 1–8 mA/cm^2).

3.5. Effect of time

At the experimental conditions listed in Table 2, electrochemical experiments are carried out as a function of time levels ranging from 5 to 40 min. As time passes, the effectiveness of nitrate elimination improves. Fig. 6 shows the final findings. When the current density is increased from 5 to 40 min, the mean nitrate removal rises from 33% to 100% in the case of Zn–Cu as anode–cathode electrodes.

3.6. Oxidation reduction potential

At the experimental circumstances listed in Table 2, Fig. 7 depicts the impact of anode and cathode electrode materials on the ORP value. At comparable experimental circumstances, As–As anode–cathode electrodes generate the mean of the lowest ORP value (+8 mV), while Zn–Cu anode–cathode electrodes create the mean of the greatest ORP value (–338 mV) (Table 2).

3.7. Kinetic studies

Fig. 7 depicts plots of kinetics first and second order reaction models fitted to nitrate removal experimental data in a batch electrochemical reactor under the parameters

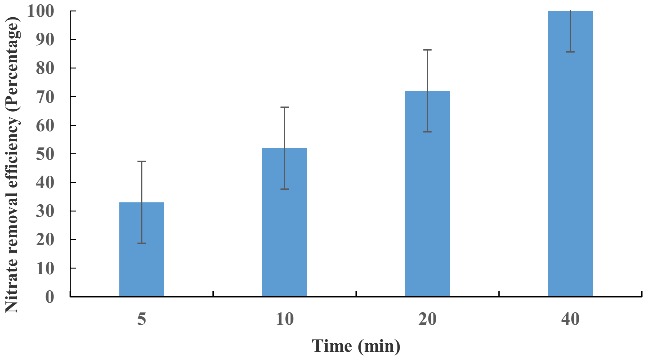

Fig. 6. The impact of time on the nitrate removal in the batch electrochemical reactor (experimental conditions: 20°C; pH: 8; reaction time: 5–40 min; current density: 8 mA/cm^2).

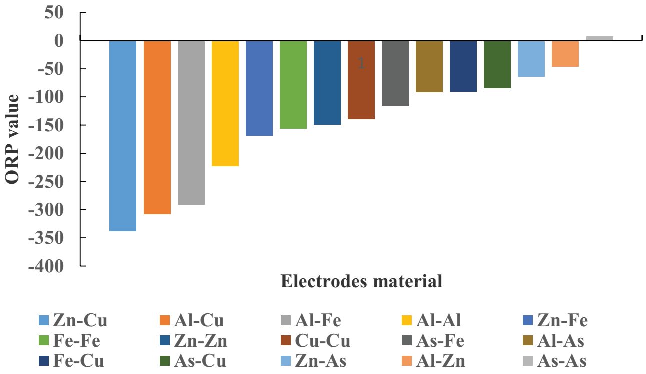

Fig. 7. The impact of electrodes material on the ORP value in the batch electrochemical reactor (experimental conditions: 20°C; pH: 8; reaction time: 40 min; current density 8 mA/cm^2).

listed in Table 2. The experimental results were more consistent with a first-order response. The Taguchi model's findings for nitrate removal efficiency revealed that response time was the most relevant variable.

4. Discussion

The electrode material has a significant impact on nitrate removal in the electrochemical reactor. As a result, the optimal material will be one that has an oxidation reduction potential just high enough to convert nitrate to nitrogen (gas). For the research of reactive black 5 removals, Saxena and Ruparelia [26] use Ti/SnO$_2$-Sb$_2$O$_5$, commercial MMO, and Ti/CeO$_2$-RuO$_2$-SnO$_2$-Sb$_2$O$_5$ anode electrodes. Under the testing circumstances used (reaction duration of 40 min, reactive black 5 concentration of 1 g/L, and pH of 2), current efficiency for Ti/SnO$_2$-Sb$_2$O$_5$, commercial MMO, and Ti/CeO$_2$-RuO$_2$-SnO$_2$-Sb$_2$O$_5$ anodes is 10%, 20%, and 15%, respectively. It's possible that the higher removal with aluminium and iron electrodes is due to their larger electron donating ability. When compared to other metals, steel is a weak electron donor. Kim et al. [27] found that Fe electrodes removed more chromium (Cr^{+6}) from synthetic metal plating effluent than Al electrodes in a reactor. Majlesi et al. [28] found that Al–Al electrodes removed 96% more nitrate from water samples than Fe–Fe electrodes (87%) in an electrochemical reactor under the same experimental circumstances (reaction period of 30 minutes, current density of 3.2 mA/cm^2, and pH of 7). After testing electrode materials such as Ti/PbO$_2$, Ti/IrO$_2$, Ti/RuO$_2$, and biochemical oxygen demand for treatment of typical industrial wastewater, Yao et al. [29] claim that Ti/PbO$_2$ anode is the best for chemical oxygen demand and NH_4^+ elimination. Barzegar et al. [30] claim that electrocoagulation (EC) with Fe electrode exhibited high catalytic activity for ozone activation in contrast with Al electrode. The pH of the water has a big impact on nitrate removal in the electrochemical reactor. During the procedure, the pH level fluctuates. The pH change range is determined by the electrodes used and the original pH of the samples. When the pH is raised from 6 to 7, the mean nitrate removal gradually rises. When the pH is raised from 7 to 8, the mean nitrate removal rises dramatically. The fact that electrochemical efficiency is a function of pH is supported by this discovery. Yang et al. [31] report the maximum nitrate reduction at pH 7 in an electrochemical rector using a Co/AC$_{0.9}$-AB$_{0.1}$ electrode and a continuous current of 400 mA for 1 h. According to Yao et al. [32], the maximum ammonia reduction was achieved at pH 8.3 in an electrochemical oxidation reactor using a Ti/PbO$_2$ electrode and a current density of 20 mA/cm^2.The following is a description of a proposed electro reduction method for nitrate removal: The principal reaction at the anode of an electrochemical reactor is oxygen evolution:

$$4OH^- \leftrightarrow O_2 + 2H_2O \tag{4}$$

The main reaction at the cathode is hydrogen evolution:

$$2H_2O + 2e^- \leftrightarrow H_2 + 2OH^- \tag{5}$$

The electrochemical reaction of nitrate is nitrogen gas evolution:

$$4NO_3^- + 2H_2O \leftrightarrow 2N_2 + 5O_2 + 4OH^- \tag{6}$$

Consumed water acidity increases as a result of nitrate reduction, resulting in an increase in noticeable water pH. At high current densities, the amount of energy consumed over time increases, and as a result, anodic and cathodic activities increase, and the rate of reduction of the water molecule at the cathode increases sharply, causing the amount of hydroxide ions in the sample to increase dramatically, and the rate of hydrogen ions evolution into the environment as H_2 gas to increase, resulting in an increase in pH. Similar findings are reported by Rajic et al. [33]. According to Gao et al. [34], water pH levels have a significant influence on total nitrogen removal. The current density has an impact on the efficiency and performance of nitrate removal in an electrochemical reactor. The consumption of electrical energy rises as the applied current density rises, yet this rise is correlated to some degree with nitrate anion elimination efficiency. It seems to justify the use of larger current densities to eliminate pollutants. According to pre-test data,

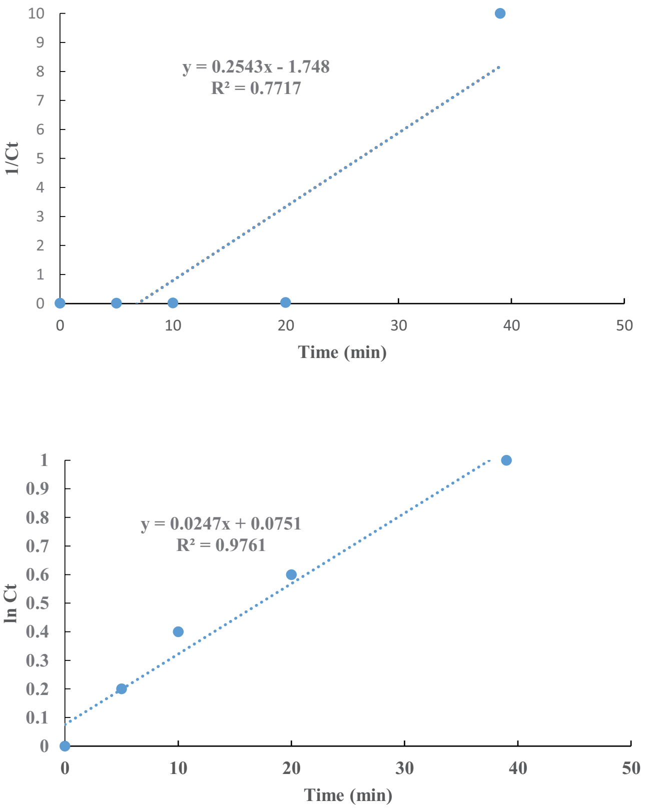

Fig. 8. The plots of first, and second-order reaction models fitted with the nitrate removal experimental data in batch electrochemical reactor (experimental conditions: 20°C; pH: 8; reaction time: 5–40 min).

the current density efficiency of Al–Al, Fe–Fe, and As–As electrodes is 22%, 15%, and 3%, respectively. The increase in anode dissolution rate as a consequence of increased current density and reaction time was linked to the production of N_2 gas in the electrode due to the Faraday low. The Al electrode generates more N_2 gas and does so more quickly than the Fe and as electrodes. When H_2 bubbles develop on the cathode, another solids removal process called electroflotation (EF) occurs, which lifts light solid particles to the top and forms a thick foam layer [35]. The current density has a big impact on nitrate removal in the electrochemical reactor. The rate constant of the pseudo-first-order for mitoxantrone (MXT) is raised from 0.0555 to 0.0845 when the current density is increased from 100 to 450 mA, according to Jafarizad et al. [36]. The rate of hydrogen gas evolution in the cathode electrode is proportional to the rise in mean nitrate removal as a consequence of increased current density (Cu). As a result, based on the methods described, hydrogen gas evolution is boosted, increasing the reduction conditions and rate of nitrogen gas development. The nitrate removal rate is proportional to the nitrate content in the water as a function of current density. The rate of growth in the consumed anode is proportional to the rise in mean nitrate removal as a consequence of increased current density (Zn). The mean anode weight loss from 3 to 9 mg as a consequence of increasing the current density from 1 to 3 mA/cm^2 may be calculated using a linear equation. Liu et al. [37] used a pine pollen produced carbon electrode with potentials of 1.4, 1.6, 1.8, and 2.0 V and found that the greatest adsorption rate of 0.56 mg/g min was achieved at 2 V. According to Yao et al. [38], when current density increases from 5.0 to 12.5 mA/cm^2, the chemical oxygen demand (COD) and total nitrogen (TN) removal efficiency increases from 78.4% to 95.3% and from 72.6% to 86.0%, respectively [38]. Because one of the most significant factors in choosing a suitable process for the removal of pollutants is the cost of the process, the electrode consumed is weighed after each set of electrode tests, and the amount of the electrode consumed was determined under various situations. The consumption electrode and energy expenses are a substantial loss or profit in the economic part of the process [39]. The mean anode weight loss from 9 to 23 mg as a consequence of a 3–9 mA/cm^2 increase in current density never follows a linear equation. The length of time that may be ascribed to increased opportunity for adsorption/desorption reactive material specious and blocking current is linked to the rise in mean nitrate removal as a consequence of increasing current density. The quantity of anode consumed in the solution determines the efficacy of nitrate ion removal. Because the quantity of anode used is dependent on both the reaction time and the applied current density, the removal of nitrate becomes more complete when one of these two factors rises. As a result, with larger current densities and response durations, ion removal efficiency may be improved. According to Bazrafshan and Mahvi [40], increasing the applied voltage from 10 to 60 V increases the mean electrode consumption from 0.14 to 0.56 kg/m^3. The doping technique, according to Guo et al. [41], results in a lower consumption electrode. According to Ebba et al., the Al–Al electrode combination consumes less energy than the Fe–Fe electrode combination [42]. The increase in mean nitrate removal with time is predicted and may be related to the amount of pH increase as the electrochemical reaction time increases. The removal efficiency improves dramatically as the current density delivered to the process increases for a given response time. The quantity of nitrate ion removal was discovered to be a function of reaction duration, current density, and electrode type in this study. The decrease of nitrate ions is dependent on the time of electrochemical purification and the starting concentration of nitrate ions, according to this research. In fact, as seen in Fig. 6, the biggest drop in nitrate occurred in the first 20 min. On the other hand, the removal efficiency progressively improved with time, reaching its peak in 40 min for all samples. Malinovic et al. [43], Rodziewicz et al. [44], and Hooshmandfar et al. [45] have all shown similar impacts of the electrochemical reaction time when treating nitrate contaminants. Increased removal efficiency is achieved by increasing current density and duration of electrolysis owing to quicker creation of electrolysis products such as hydrogen at the cathode and higher reducing conditions. The best period for anionic surfactant removal by electrochemical method, according to Mohebrad et al. [46], is 60 min. Nitrate seems to quickly convert to products such as nitrogen gas in a strong reducing environment (ORP –338 mV) using Zn–Cu as anode–cathode electrodes. In an electrochemical Fenton-type procedure, Kishimoto et al. [47] found that ORP is reduced by 100–140 mV at high current efficiency. In the optimal circumstances for nitrate removal (pH 7, 30 V, 100 mg/L nitrate starting concentration, and 150 min reaction time), Masoumbeigi et al. [48] report that Al–Al electrodes have ORP equal to –223. ORP is altered 220 to –375 mV, according to Hossini and Rezaee [49], and this range is acceptable for denitrification and nitrate reduction. Lackner et al. [50] observed that the working ORP for nitrification and denitrification is –100 to +100 mV. When predicted, as the correlation coefficient (R^2) rises, the experimental data fit better. In the batch electrochemical reactor, the first order reaction rate constant for nitrate reduction is 0.69 L/g·min. Chemical reactions on the electrode surface are confirmed by the first order reaction. The experimental results fit better to the first order reaction, according to Chen et al. [51]. The experimental results fit better to the second order reaction, according to Jadhao et al. [52]. The experimental results match better to a Langmuir–Hinshelwood adsorption model, according to García-Prieto et al. [53]. Hou et al. [54] propose a phase-reaction kinetics model for simulating methyl orange (MO) COD elimination efficiency. Ghanbari et al. [55] propose a reaction kinetic of nitrate removal in the absence and presence of turbidity is first-order and zero-order, respectively.

5. Conclusions

In a batch and mono-polar electrodes connection mode, the chemical reduction of nitrate from urbane drinking water is examined in an electrochemical reactor. The impacts of many operational factors on process reduction efficiency are investigated. The tests resulted in the following conclusions:

- Using Zn–Cu as anode–cathode electrodes results in the most nitrate reduction (100%).
- Nitrate reduction is affected by pH, with the greatest decrease occurring at pH 8.
- Using Zn–Cu as anode–cathode electrodes, the 8 mA/cm^2 current density obtains the greatest nitrate removal during the reactor (100%).
- As the current density rises, the anode's consumed mass rises as well.
- Reaction time has a major impact on nitrate reduction throughout the process; for given experimental settings, nitrate reduction improves as reaction time increases.
- At comparable experimental circumstances, Zn–Cu as anode–cathode electrodes yield the mean of the greatest ORP value (–338 mV).
- During reactor operation, nitrate reduction follows a first-order rate equation. The removal process is linked to rising reduction conditions at the cathode as a consequence of hydrogen evolution.
- The electrochemical reactor was shown to be an efficient and practical method for achieving a high degree of nitrate reduction from drinking water in batch and mono-polar electrodes connection mode, and to be a promising technique for treating nitrate-polluted drinking water.
- There is a need for fresh research into alternative elimination methods that aren't included in the studies. Investigation of copper and zinc ion residues in water after electrolysis is suggested due to causing the health hazards on the body of the water user.

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Conflict of interests

The authors of this article declare that they have no conflict of interests.

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