

Sorption of trace levels of bromate by macroporous strong base anion exchange resin: Influencing factors, equilibrium isotherms and thermodynamic studies

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HIGHLIGHTS

- D201-Cl resin exhibited greater bromate adsorption capacity.
- The adsorption kinetics agreed with the pseudo-first-order model.
- The equilibrium data can be well described by Freundlich and Redlich–Peterson model.
- The resin showed excellent regeneration performance and reusability.

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ABSTRACT

Bromate, a cancerogenic disinfection by-product (DBP), has been increasingly concerned in recent years. In this study, macroporous Cl-type strong base anion exchange resin (D201-Cl) was used to remove trace levels of bromate from aqueous solution. Batch sorption experiments were performed to evaluate the influence of various factors such as initial bromate concentration, contact time, solution initial pH and temperature on the uptake of bromate. D201-Cl resin exhibited higher bromate removal efficiency (residual concentration of bromate was under the maximum contaminant level (MCL) of $10 \mu\text{g}\cdot\text{L}^{-1}$ at all conditions investigated) and broader pH scope of application (4.50–9.92). The maximum sorption capacity reached to $105.5 \text{ mg}\cdot\text{g}^{-1}$ at 298 K. The kinetics data were well described by pseudo-first-order kinetic model, and Freundlich isotherm model and Redlich–Peterson isotherm model fitted the sorption isotherms ($R^2 > 0.99$). Thermodynamic analysis showed that the sorption process was spontaneous and endothermic. In addition, D201-Cl resin still maintained high bromate removal efficiency after regenerated by 0.1 M NaCl solution for five cycles. The results indicate that D201-Cl resin is a low-cost and efficient sorbent for bromate removal from drinking water, especially for trace levels of bromate.

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1. Introduction

Bromate (BrO_3^-), a typical disinfection by-product (DBP), is generally formed during ozonation processes of natural water containing bromide (Br^-) [1,2]. In general, the concentration of bromate in drinking water ranges from 0.4 to $100 \mu\text{g}\cdot\text{L}^{-1}$ [3,4]. Bromate poses potential health risks and has been verified to induce renal cell tumors, mesotheliomas of the peritoneum, and follicular cell tumors of the thyroid [5], which has been classified as a possible carcinogen by United States Environmental Protection Agency (US EPA) [6]. The specified maximum contaminant

level (MCL) of bromate of $10 \mu\text{g}\cdot\text{L}^{-1}$ for drinking water has already been implemented in the USA, U.K., Canada, Japan and China [7–9]. Thus, it is necessary to reduce the concentration level of bromate in drinking water.

Many chemical, physical and biological methods have been employed to remove bromate from aqueous solution, such as reduction by zero-valent iron [10], adsorption using activated carbon [11,12], filtration by ceramic membrane [13], destruction by photocatalytic decomposition and UV irradiation [14], high-energy electron beam (HEEB) irradiation [15] and biological removal or reduction through membrane bioreactors [16]. However, some disadvantages, including high operational and maintenance costs, generation of secondary wastes such as toxic sludge and iron ion, and complicated regulation procedures limit their application. Comparatively, the adsorption technology has been considered as an economical, efficient and environment-friendly

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technology in wastewater treatment [17]. Several adsorbents such as activated carbon (AC) [11], granular ferric hydroxide (GFH) [18] and organo-montmorillonite [19] have been successfully applied for bromate removal. Wang et al. investigated the removal of bromate by various powdered activated carbons (PAC) prepared from different raw materials [12]. Farooq et al. modified the PAC by cationic surfactants and found that surfactant-modified PAC exhibited 3 times higher bromate adsorption capacity than untreated AC [20]. Although AC is widely used for its excellent adsorption effect, high cost sometimes restricts its use. The difficult preparation also limits the application of GFH and organo-montmorillonite. Thus, it is becoming the focus to select efficient materials that are more cost-effective for bromate adsorption.

Polymeric anion exchangers become the attractive materials for adsorbing phosphate [21], perchlorate [22], arsenate [23] and inorganic anions [24], because they are commercially available, very cheap, conveniently regenerated and chemically stable over a wide pH range. Ding et al. chose magnetic ion exchange (MIEX) resin as bromide sorbent and found that the maximum sorption capacity was $11.51 \text{ mg} \cdot \text{mL}^{-1}$ resin for bromide [25]. Kim et al. have developed a high-performing polymeric anion-exchange resin for the removal of nutrients such as phosphate, nitrate, and fluoride from water [21,24]. Clayton J. Johnson [26] also illustrated impact of MIEX resin on ozone demand and bromate formation during drinking water treatment. But the application of polymeric anion exchanger to eliminate bromate, especially trace levels is lack of attention.

In present study, the macroporous strong base anion exchange resin with polystyrene matrix, quaternary amine functional groups, and chloride as exchange ion (D201-Cl), have been successfully used for the removal of trace levels bromate from aqueous solutions. To evaluate the removal characteristics of bromate by D201-Cl resin, the effects of different factors such as initial bromate concentration, contact time, solution initial pH, temperature and competing anions were investigated. Adsorption kinetics, equilibrium isotherm and thermodynamics were also performed. Finally, regeneration and reusability of the sorbents were evaluated.

2. Materials and methods

2.1. Materials

D201-Cl resin was purchased from Dayu Chemical Co. Ltd. (Changsha, China). This product is a macroporous, strong base anion exchange resin with polystyrene matrix, quaternary amine functional groups, and chloride as exchange ion. And the average diameter of resin particles is 0.7 mm. The resin was washed with Milli-Q ultrapure water and ethanol to remove the impurities before used, then pretreated with hydrochloric acid, ultrapure water and sodium hydroxide by turns to ascertain that resin was chloride type. Stock solutions of bromate were prepared by dissolving solid NaBrO_3 (Shanghai Chemical Reagent Co. Ltd., China) in ultrapure water.

2.2. Analytical methods

The bromate and other anion were measured by ion chromatography (Dionex ICS-900, USA) equipped with a suppressed conductivity detector. 9.4 mM sodium carbonate (Na_2CO_3) and 1.8 mM sodium bicarbonate (NaHCO_3) was used as the effluent at a flow rate of 1.0 mL/min. The sample was injected through a built-in needle port in the panel of the ion chromatography with six-port sample injection valve. The separation column (Dionex IonPac AS19, 4.0 mm ID $\times$ 250 mm) was operated at 40 °C.

2.3. Batch experiments

All equilibrium sorption experiments were carried out at 298 K and the initial solution pH was controlled at 7.00 ± 0.50 . 0.5 g D201-Cl resins were added to a set of capped glass flasks containing 500 mL

bromate solutions with initial concentrations of 200, 400, and $600 \mu\text{g} \cdot \text{L}^{-1}$, respectively. The flasks were agitated in a thermostated rotary shaker at 150 rpm. At specified time intervals, an aliquot of sample was filtered using $0.22 \mu\text{m}$ disposable membrane filters and analyzed for the concentration of bromate by ion chromatography. Reproducibility of the measurements was determined in triplicates, and the average values were reported.

The procedure of independent factor studies was similar to that of equilibrium sorption experiments, except that the contact time was 300 min. The effect of initial pH (3.16–10.90) and temperature (298, 313 and 328 K) on bromate removal was investigated. In order to determine the effect of each parameter, other parameters were fixed. The initial pH values of bromate solutions were adjusted by the addition of 0.1 M sulfuric acid (H_2SO_4) or 0.1 M sodium hydroxide (NaOH) according to the need.

The sorption capacity of resin and solid–liquid distribution coefficient of bromate on D201-Cl resin and solution after sorption were determined by the following equations (1) and (2):

$$q_t = \frac{(C_0 - C_t)V}{W} \quad (1)$$

$$K_D = \frac{(C_0 - C_t)}{C_t} \times \frac{V}{W} \quad (2)$$

where, q_t is the bromate sorption capacity of resin at time t , C_0 ($\mu\text{g} \cdot \text{L}^{-1}$) and C_t ($\mu\text{g} \cdot \text{L}^{-1}$) are the initial bromate concentration and bromate concentration at time t ($\mu\text{g} \cdot \text{L}^{-1}$), respectively. V (L) is the volume of solution and W (g) is the mass of the resin. K_D is the solid–liquid distribution coefficient of bromate on D201-Cl resin and solution after sorption.

2.4. Regeneration and reusability studies

The feasibility of regenerating D201-Cl resin to repeated use was investigated by using sodium chloride as stripping agent. Actually, the D201-Cl resin saturated with bromate was added into 0.1 M NaCl solution for desorption at 150 rpm at room temperature for 12 h. Then the sorbent was separated and washed by ultrapure water for several times until neutral, so that the reuse capacity of resin for bromate removal could be determined again.

3. Results and discussion

3.1. Effect of contact time and initial bromate concentration

The bromate removal by D201-Cl resin was investigated as a function of contact time at different initial bromate concentrations (200, 400 and

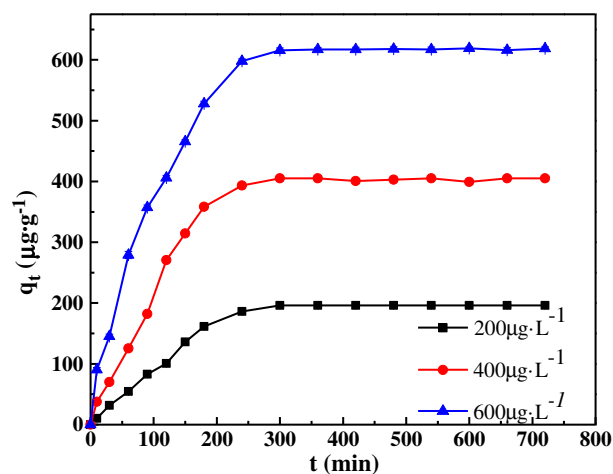


Fig. 1. Effect of contact time and initial bromate concentration on bromate removal (adsorbent dosage = $1.0 \text{ g} \cdot \text{L}^{-1}$, temperature = 298 K, pH = 7.00).

Table 1
Pseudo-first-order model parameters for bromate adsorption on D201-Cl resin.

C_0 ($\mu\text{g}\cdot\text{L}^{-1}$)	q_e ($\mu\text{g}\cdot\text{g}^{-1}$)	k (min^{-1})	R^2	SD (%)
195.96	260.07	0.012	0.9743	0.23
404.99	597.62	0.014	0.9798	0.21
624.59	1040.68	0.018	0.9570	0.46

$600\ \mu\text{g}\cdot\text{L}^{-1}$). From Fig. 1, it was obviously seen that the sorption of bromate on D201-Cl resin was divided into two stages. At initial stage, the sorption of bromate on D201-Cl resin gradually increased with increasing contact time because of the greater concentration gradient between the bromate solution and the surface of resin [27]. Subsequently, the sorption reached apparent equilibrium after about 4 h along with the decline of concentration difference between the liquid and solid phase. There was no significant change in bromate sorbed on D201-Cl resin in the following 10 h. A similar trend was observed during the sorption of trace levels of bromate by other sorbents [12,19].

The effect of initial bromate concentration on equilibrium time was investigated and results are also shown in Fig. 1. When the initial bromate concentration increased from 200 to $600\ \mu\text{g}\cdot\text{L}^{-1}$, the sorption capacities of bromate increased from 195.96 to $618.70\ \mu\text{g}\cdot\text{g}^{-1}$. Meanwhile, the time to reach equilibrium was little shortened with the increase of initial bromate concentration. This phenomenon can be explained that the initial bromate concentration provides the necessary driving force to overcome the resistance to the mass transfer of bromate between the aqueous and solid phases [28].

An adsorption kinetic model can be used to estimate adsorption rate. According to the correlative with the behavior over the whole range of adsorption (Fig. 1), the pseudo-first-order adsorption model was applied to fit the experimental data. The kinetic rate equation can be expressed in Eq. (3):

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

where q_e and q_t are the amounts adsorbed at equilibrium and at time t , respectively. k is the rate constant of pseudo-first-order.

The parameters of pseudo-first-order model are summarized in Table 1. The plots of $\ln(q_e - q_t)$ against t for different initial bromate concentrations ($200, 400$ and $600\ \mu\text{g}\cdot\text{L}^{-1}$) are shown in Fig. 2. The high correlation coefficients $R^2 > 0.95$ demonstrated that the data conformed well to the pseudo-first-order rate model. The increase of k with an increase in the initial bromate concentration could be attributed to the driving force for mass transfer, which led more bromate molecules to reach the surface of the sorbents [29]. Our finding agreed with previous reports [24,29].

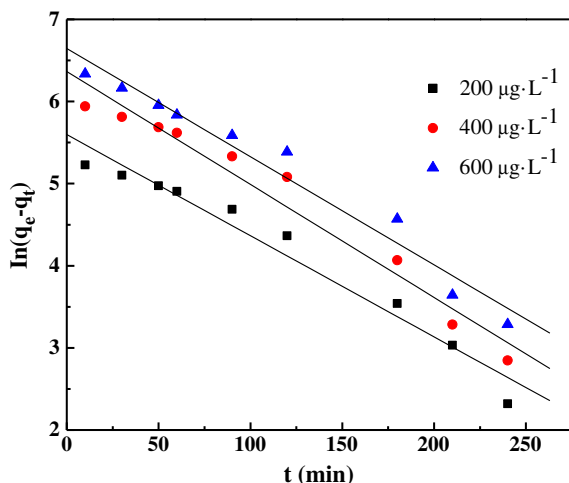


Fig. 2. Pseudo-first-order kinetic model plots for bromate sorption on D201-Cl resin.

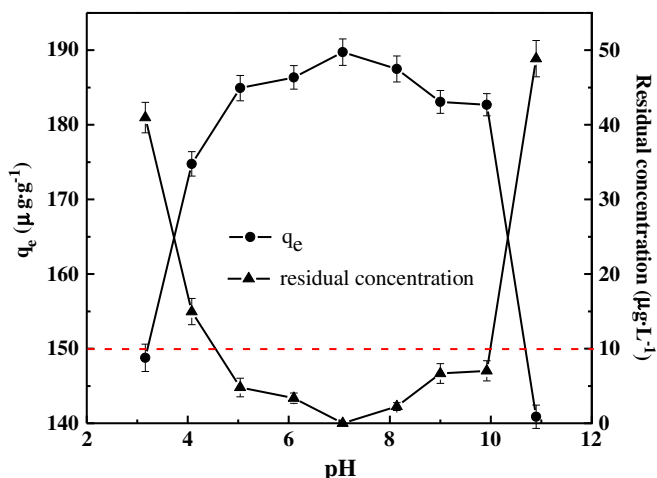


Fig. 3. Effect of initial pH on bromate removal (adsorbent dosage = $1.0\ \text{g}\cdot\text{L}^{-1}$, initial bromate concentration = $191.06\ \mu\text{g}\cdot\text{L}^{-1}$, temperature = 298 K).

3.2. Effect of initial pH

The removal trends of bromate by D201-Cl resin under different initial solution pH are shown in Fig. 3. It could be seen that the sorption of bromate on D201-Cl resin was strongly pH dependent. The sorption capacities of bromate on D201-Cl resin markedly increased with the pH increasing from 3.16 to 7.07, reaching a maximum capacity of $191.06\ \mu\text{g}\cdot\text{L}^{-1}$ at pH 7.07, subsequently, it decreased gradually with further increase in pH. The phenomenon could be interpreted by the competition between the sulfate and hydroxide ions originated from pH adjusting process and bromate on D201-Cl resin. Ding et al. found that the hydroxyls had been exchanged on the surface of MIEIX resin at pH 10.90 through Fourier translation infrared spectroscopy [25]. But in the present study, the initial pH was not obviously effect on the removal efficiency of bromate and residual concentration of bromate was under the maximum contaminant level (MCL) of $10\ \mu\text{g}\cdot\text{L}^{-1}$ while the pH varying from 4.50 to 9.92, indicating it is appropriate to remove bromate using macroporous anion resin in a wide pH range.

3.3. Effect of temperature

The effects of temperature on bromate sorption by D201-Cl at different initial concentrations were studied at 298 K, 313 K and 328 K, respectively. The sorption process didn't achieve equilibrium when the

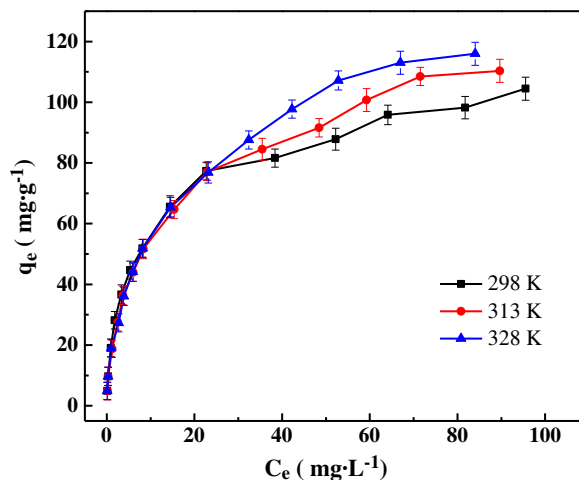


Fig. 4. Effect of initial bromate concentration and temperature on bromate removal (adsorbent dosage = $1.0\ \text{g}\cdot\text{L}^{-1}$, pH = 7.00).

initial bromate concentration was below $25 \text{ mg} \cdot \text{L}^{-1}$ as shown in Fig. 4, so the impact of temperature on bromate sorption was not obvious. When the initial bromate concentration exceeded $25 \text{ mg} \cdot \text{L}^{-1}$, the adsorption capacity of bromate on D201-Cl increased from $105.46 \text{ mg} \cdot \text{g}^{-1}$ to $115.96 \text{ mg} \cdot \text{g}^{-1}$ with the temperature increasing from 298 K to 308 K. It was well known that the viscosity of the solution decreased at higher temperature, which improved the diffusion of the bromate across the external boundary layer and in the internal

pores of the resins [30]. Therefore, the sorption process of bromate on D201-Cl resin is endothermic. The same phenomenon was also found in M1EX resin for phosphate adsorption [31].

3.4. Adsorption isotherm

Adsorption isotherms can clearly depict the interaction pathway of pollutants with remediation materials [32]. The results of sorption equilibrium of bromate on D201-Cl resin at 298 K, 313 K and 328 K are given respectively in Fig. 5. In this study, the most frequently used two two-parameter adsorption isotherm models Langmuir and Freundlich, and three-parameter adsorption isotherm model Redlich–Peterson were chosen to fit the experimental data. The Langmuir model assumes that the adsorption occurred in a monolayer and all sites were equal, whereas the Freundlich isotherm is more suitable for heterogeneous adsorption. The Redlich–Peterson is a hybrid isotherm featuring both Langmuir and Freundlich isotherms [33]. It can represent adsorption equilibria over a wide concentration range and be applied either in homogeneous or heterogeneous systems due to its versatility. Their equations were expressed by Eqs. (4), (5) and (6) [25,33]:

$$\text{Langmuir: } q_e = \frac{q_{\max} b C_e}{1 + b C_e} \quad (4)$$

$$\text{Freundlich: } q_e = K_f C_e^{1/n} \quad (5)$$

$$\text{Redlich–Peterson: } q_e = \frac{K_{RP} C_e}{1 + \alpha_{RP} C_e^{\beta}} \quad (6)$$

where q_e is the bromate adsorption capacity at equilibrium concentration C_e , $q_{\max}$ represents the maximum adsorption capacity, b is the Langmuir model constant; n and K_f are the Freundlich constants, K_{RP} and α_{RP} are the Redlich–Peterson constants, β is the Redlich–Peterson exponent (dimension).

The corresponding values of Langmuir, Freundlich and Redlich–Peterson isotherm models at different temperature were given in Table 2. As shown in Table 2, the greater correlation coefficients (>0.99) at all the temperatures indicated that the Freundlich model and the Redlich–Peterson model fit the data better than the Langmuir model in this study. It implied that the D201-Cl was heterogeneous in the liquid phase and the removal of bromate was similar to multilayer adsorption process [24]. Meanwhile, the magnitude of n in Freundlich model is an indication of the favorability and capacity of the adsorbent/adsorbate system. Values of n greater than 1 represent the favorable adsorption condition [34]. The values of n ranging from 2.53 to 3.10 in the study suggested that the adsorption of bromate on D201-Cl resin was favorable. The Redlich–Peterson model is a hybrid isotherm featuring both Langmuir and Freundlich isotherms, which

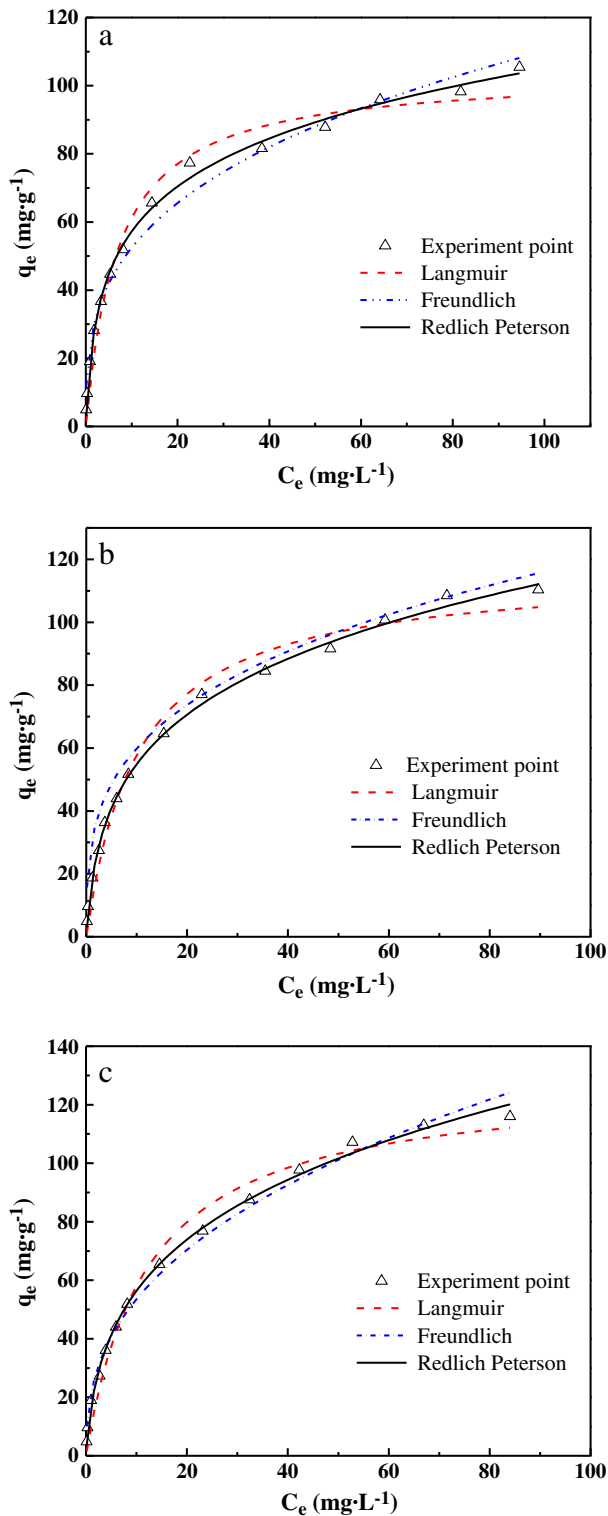


Fig. 5. Adsorption isotherms of bromate on D201-Cl resin at (a) 298 K, (b) 313 K and (c) 328 K.

Table 2
Parameters of Langmuir, Freundlich, and Redlich–Peterson models.

Isotherm model	298 K	313 K	328 K
<i>Langmuir</i>			
$q_{\max} (\text{mg} \cdot \text{g}^{-1})$	103.90	116.74	128.35
b	0.14	0.10	0.08
R^2	0.9789	0.9825	0.9837
<i>Freundlich</i>			
K_f	21.49	22.10	24.93
n	3.10	2.70	2.53
R^2	0.9803	0.9881	0.9902
<i>Redlich–Peterson</i>			
K_{RP}	37.88	29.68	30.05
α_{RP}	0.90	0.79	0.83
β	0.80	0.75	0.72
R^2	0.9968	0.9975	0.9971

Table 3
Comparison of bromate adsorption with different materials.

Material	Initial conc. (mg·L ⁻¹)	Equilibrium conc. (mg·L ⁻¹)	Adsorbent dosage (g·L ⁻¹)	q_{max} (mg·g ⁻¹)	Ref.
Zero-valent iron	0.1	0	25		[10]
Powdered activated carbon	0.1	>0.01	0.2	99.6	[12]
Granular ferric hydroxide	10.0	0.4	10	16.5	[18]
Organo-montmorillonite	0.1	<0.01	1	0.089	[19]
CACQS	0.2	0.05	100	0.038	[35]
Crystalline akaganéite	10.0	1	1	39.4	[36]
Nano-Al ₂ O ₃	5.0	3	1	6.0	[37]
Macroporous anion resin	0.2	<0.01	1	105.5	Present study

approaches Freundlich isotherm model at high concentration (as the values of β tends to zero) and is in accordance with the Langmuir model at low concentration (as the values of β are all close to one) [33].

The maximum bromate adsorption capacity of macroporous anion resin was 105.46 mg·g⁻¹, 110.35 mg·g⁻¹, 115.96 mg·g⁻¹ respectively at 298, 313, 328 K, which was notably greater than other adsorbents reported in previous literatures [10,12,18,19,35–37] (shown in Table 3). In addition, an equilibrium bromate concentration under 10 µg·L⁻¹, the standard for drinking water, could be achieved by D201-Cl resin with initial bromate concentration ranged from 200 to 600 µg·L⁻¹, which indicated that D201-Cl resin had a significant potential for bromate removal from drinking water, especially for trace levels.

3.5. Adsorption thermodynamics

In order to understand the sorption process from the aspect of energy change, three basic thermodynamic constants: standard free energy change (ΔG° , kJ·mol⁻¹), standard enthalpy change (ΔH° , J·mol⁻¹ K⁻¹) and standard entropy change (ΔS° , kJ·mol⁻¹) were chosen in the thermodynamics analysis. These constants can be calculated by the following equations:

$$\ln K_D = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \quad (7)$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (8)$$

where K_D is the distribution coefficient calculated by Eq. (2), R is universal gas constant (8.314 J·mol⁻¹ K⁻¹), and T is the temperature in Kelvin (K). The results at different temperature are listed in Table 4.

The values of ΔG° were found to be negative at all temperatures, suggesting that the sorption of bromate on D201-Cl resin was spontaneous and thermodynamically feasible [38]. Meanwhile, the ΔG° values became more negative with the temperature increasing from 298 K to 328 K, indicating that higher temperature favored the sorption of bromate on resin, which was consistent with the results in Section 3.3. The positive ΔH° value (5.75 kJ·mol⁻¹) showed that the heat was released during the sorption, suggesting that the interaction between bromate and D201-Cl resin was endothermic reaction. In addition, the ΔS° was calculated to be 20.18 J·mol⁻¹ K⁻¹, which on the one hand showed the affinity of the sorbent for bromate, on the other hand, indicated the increase in randomness at the solid/liquid interface after adsorption [39].

Table 4
Thermodynamic parameters of bromate adsorbed on resin.

T (K)	K_D	ΔG° (kJ·mol ⁻¹)	ΔS° (J·mol ⁻¹ K ⁻¹)	ΔH° (kJ·mol ⁻¹)
298	1.12	-0.27		
313	1.23	-0.54	20.18	5.75
328	1.38	-0.88		

3.6. Effect of co-existing anions

The conventional anion present in drinking water, such as chloride, nitrate and sulfate might compete with bromate for the active sorption sites on resin. In this study, the effects of different co-existing anions (Cl⁻, NO₃⁻ and SO₄²⁻) on bromate removal were investigated with different initial concentrations of competing anions (50–250 mg·L⁻¹) at room temperature (298 K) and the results are shown in Fig. 6. The adsorption capacity of bromate on D201-Cl was 195.96 µg·g⁻¹ when no other anion was added. When chloride, nitrate and sulfate were added at initial concentration of 50 mg·L⁻¹, the adsorption capacity of bromate decreased markedly to 150.13, 140.29 and 142.62 µg·g⁻¹ respectively. With the increase of the concentration of coexisting anion, the adsorption capacity of bromate reduced gradually. These results showed that the competition between co-existing anions and bromate for the sorption active sites of D201-Cl resin was very strong. But the impact of co-existing anions on bromate removal was different and the following order was obtained: NO₃⁻ > SO₄²⁻ > Cl⁻, which may be explained with the hydration energy of anion. For example, the hydration energy of NO₃⁻ (ΔG° , -300 kJ·mol⁻¹) was lower than Cl⁻ (ΔG° , -340 kJ·mol⁻¹) and SO₄²⁻ (ΔG° , -1080 kJ·mol⁻¹) [40]. Previous research has proved that lower hydration energy is more favorable for ion exchange [41]. The weaker impact of Cl⁻ should be attributed that chloride ion itself was the exchange ion.

3.7. Regeneration and reusability

The benefit of sorption process is that the used sorbent can be regenerated after reaching its capacity. For this purpose, D201-Cl resin saturated with bromate was regenerated by 0.1 M sodium chloride.

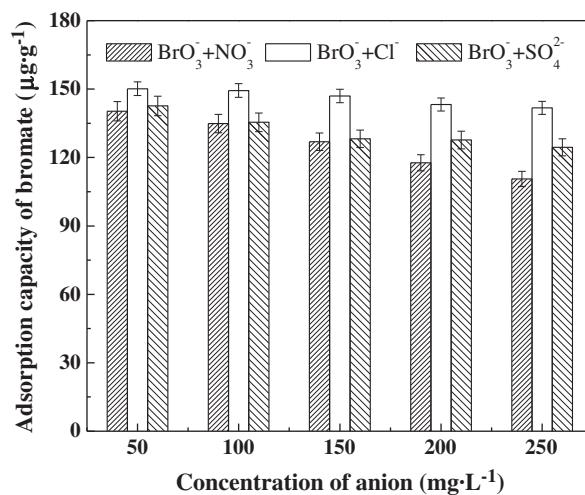


Fig. 6. Effect of coexistent anions on bromate removal (adsorbent dosage = 1.0 g·L⁻¹, temperature = 298 K, initial bromate concentration = 195.96 µg·L⁻¹, contact time = 12 h).

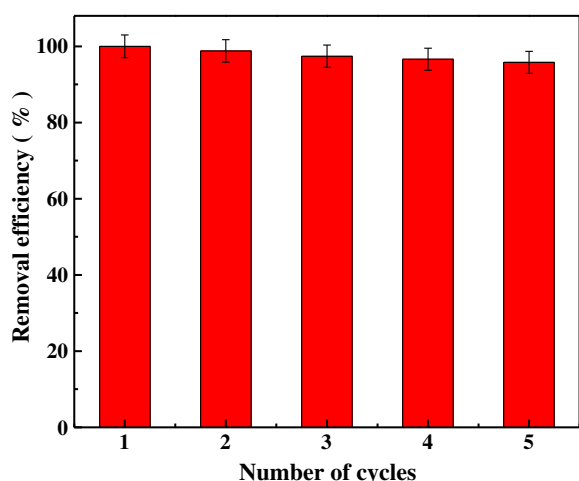


Fig. 7. Reusability efficiency of regenerated resin for five cycles (adsorbent dosage = $1.0 \text{ g} \cdot \text{L}^{-1}$, temperature = 298 K, initial bromate concentration = $198.31 \mu\text{g} \cdot \text{L}^{-1}$, contact time = 12 h).

The performance of the regenerated resin was evaluated over five successive cycles. Fig. 7 shows the reusability efficiency of D201-Cl resin for bromate sorption. The highest removal efficiency (over 99%) was obtained at first cycle because the resin was fresh. Then the removal efficiency dropped slightly from 99 to 96% in subsequent cycles, but the effluent concentration was still under the maximum contaminant level (MCL) of $10 \mu\text{g} \cdot \text{L}^{-1}$. This demonstrated that D201-Cl resin had high reusability and was a perfect sorbent for bromate removal from drinking water, especially for trace levels of bromate.

4. Conclusions

In this research, macroporous Cl-type strong base anion exchange resin (D201-Cl) was applied to remove the trace levels of bromate from aqueous solutions. The resin showed an effective performance for bromate removal and the adsorption capacity increased with the increase of the initial bromate concentration and temperature of solution. The sorption efficiency was slightly affected by the solution pH and the maximum bromate sorption was found at pH 7.07. The maximum capacity of bromate on resin was $105.5 \text{ mg} \cdot \text{g}^{-1}$ at 298 K. The coexisting anions had significant effect on bromate removal, and the following order was obtained: $\text{NO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$. Kinetic results indicated that the sorption process can be defined by the pseudo-first-order kinetic model under the investigated concentration range. The sorption equilibrium data at 298 K, 313 K and 328 K all can be best described by the Freundlich and Redlich–Peterson isotherm models. The thermodynamic results showed that the sorption on bromate was spontaneous and endothermic process. Besides, the D201-Cl resin could be regenerated by 0.1 M sodium chloride and maintained higher reusability for up to five cycles.

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