Mg/Al double-metal hydroxide regeneration of anion exchange resin by electric field intensification

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ABSTRACT

Fouled anion exchange resins were regenerated by electric field intensification of Mg/Al double-metal hydroxides. Regenerative experiments were performed with varying voltages (10–30 V) and dosages of Mg/Al hydroxides (0.045–0.135 mol and 0.015–0.045 mol, respectively) for 1–5 h. Optimal results were obtained under the following regenerative conditions: 20 V, 4 h, and 0.09/0.03 mol of Mg/Al hydroxides. The maximum regenerative capacity of resins was increased to 41.07%. The regenerative mechanism was presented by Fourier-transform infrared spectrum of resins and Mg/Al hydroxides, and the regenerative degree was analyzed with respect to conductivity, pH value, and electric current. Mg/Al hydroxides were also recycled after the regeneration. This method was proven to be cost-effective and environmentally friendly.

Key words | electrolysis, ion exchange, regeneration times, sols, voltage

INTRODUCTION

Ion exchange resins are widely used to produce demineralized water and purified water (Yeon et al. 2003; Kus et al. 2014) with improved chemical stability, mechanical strength, and exchange capacity. However, as the retention process occurs, the amount of water used increases, the quality of effluent water decreases, the water volume produced in a cycle constantly decreases, the color of the resins deepen, and the ion exchange capacity of the resins quickly declines. These observations indicate fouling of the resins (Greluk & Hubicki 2011; Hammad et al. 2014; Li et al. 2014; Piirschel et al. 2014). If measurements are not promptly determined, the resins can become susceptible to degradation, and worse, discarded. Thus, regeneration of fouled resins is of particular importance.

Resin is fouled by inorganic anions, including CO$_3$$^2$-, SO$_4$$^2$-, and Cl$^-$, as well as organic compounds with negatively charged groups, such as fulvic, humic, and gallotannic acid (Kus et al. 2014). These inorganic anions basically replace the functional groups on the resins; the negatively charged groups undergo an electrical composite reaction with fixed groups carrying positive charges on the resins to be tightly adsorbed at exchangeable positions.

Acid and alkali chemical regeneration of resins is widely practiced; for example, traditional regeneration of anion exchange resins (AERs) uses alkaline salt solutions, such as NaCl and NaOH (Jackson & Bolto 1990), with a considerable amount of concentrated solution. Concentrated ammonium bicarbonate (Chandrasekara & Pashley 2015) was recently used as regeneration salt. These methods present several advantages but also feature a number of disadvantages, including significant increases in the operating and environmental costs of the system, which aggravates water pollution and leads to resource wastage (Li et al. 1998; Greenleaf & SenGupta 2012). As an alternative to those methods, electrodeionization, electroregeneration, and electrodialysis, among others, can be used (Mahmoud et al. 2003; Govindaraj & Pattabhi 2005; Song et al. 2005; Narbaitz & Karimi-Jashni 2009), and have been applied in water treatment. Compared with the traditional chemical regeneration of resins, electrochemical regeneration clearly exhibits benefits with respect to resource resumption, environmental effect, cost efficiency, and operational management (Wang 2002, 2005).

The present study’s objective is to evaluate resin regenerant with the use of Mg/Al double-metal hydroxides and electric field, a technique that is cost-effective and environmentally friendly (Liu et al. 2008, 2012; Li et al. 2011, 2012). Resin beads were regenerated by reacting the electric field and regenerant, thereby renewing the ion exchange capacity of AERs.

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MATERIAL AND METHODS

Experimental materials and instruments

The evaluated resin, AER with a 201 × 7 strong basic styrene skeleton, was used to remove anions to obtain industrially pure water and deionized water in a specific water purification system. This system was mainly fouled by inorganic anions such as CO$_3^{2-}$, HCO$_3^-$/CO$_2$, SO$_4^{2-}$/CO$_2$, and Cl$^-$/CO$_2$. All chemicals used in this study were of analytical grade and obtained from Chinese Xilong Chemical Co., Ltd. A self-made microporous titanium filter electrode was selected as the anode; the performance data of this electrode are shown in Table 1. This electrode can improve the following properties: chemical durability, porosity, acid and alkali resistance, oxidation resistance, and compactness (Li et al. 2009). A stainless steel sleeve was used as a cathode and had a diameter of 0.1 m and a length of 0.5 m.

The following were used: DC regulated power supply, Model-DZ47-60 (Shanghai Suoyi Electronic Technology Co., Ltd, China); circulating water vacuum pump: Model-SHZ-D(III) (Yuhua Instrument Co., Ltd, China); and conductivity/TDS meter: Model-DDS-307A (Shanghai Yoke Instrument Co., Ltd, China).

Preparation of the regenerant

Mg/Al chloride, in a molar ratio of 3, and NaOH under titration reacted to obtain Mg(OH)$_2$ and Al(OH)$_3$ sols. Mg(OH)$_2$ and Al(OH)$_3$ sols were rinsed to remove Na$^+$ and Cl$^-$, which could affect resin regeneration and the effective use of the regenerant. Mg(OH)$_2$ sol was continually rinsed with deionized water until a conductivity of less than 100 $\mu$s/cm was obtained; the rinsing time was approximately 3 h. Al(OH)$_3$ sol was rinsed using the mixed-resin desalination method (Liu 2007) in accordance with the following procedure: Specific quantities of cation-exchange resins (CERs) in Al form and AERs in OH form were mixed in a ratio of 1:2; the mixed resins and Al(OH)$_3$ sol underwent pneumatic agitation as described by chemical formulas (1) and (2). The reaction was ended when a conductivity of less than 100 $\mu$s/cm was obtained and maintained for 30 min. This method greatly enhanced the desalination rate and shortened the rinsing time.

\[
R_3\text{Al} + 3\text{Na}^+ \rightarrow 3\text{RNa} + \text{Al}^3^+ \tag{1}
\]

\[
\text{ROH} + \text{Cl}^- \rightarrow \text{RCl} + \text{OH}^- \tag{2}
\]

Regeneration experiment

Figure 1 illustrates the regeneration experimental setup of the AERs with Mg/Al hydroxides as the regenerant by electric field intensification. The direction of the arrow represents one of the circulating solutions. The DC-regulated power supply is connected to the cathode/anode by titanium wires to ensure a stable output of the electric current. The procedure was executed as follows: the 100 mL fouled AERs were repeatedly rinsed with deionized water until a conductivity of less than 100 $\mu$s/cm was obtained. The prepared 200 mL Mg/Al hydroxides mixed sols and the fouled AERs were placed in a circulating solution storage container. About 3.7 L of deionized water was added to the container, and 12 L of deionized water was added to the water tank of a circulating water vacuum pump; thus, the total volume of the entire circulating solution was maintained at 16 L. The regeneration experiment was started by switching the DC power supply on, setting the operating voltage, and switching the vacuum pump on. The solution and resin in the storage container were continuously drawn into the stainless steel sleeve; here, the flow rate was controlled within 0.8–1 L/min by adjusting the inlet valve and the outlet valve of the storage container. The regeneration methods were changed, including single electrochemistry regeneration (ER), single Mg/Al hydroxide regeneration (HR), and electrochemistry combined with Mg/Al HR (EHR) at 20 V for 3 h.

Samples were taken from the water outlet of the vacuum pump every 10 min for conductivity and pH testing. The electric current and power consumption of the samples were recorded.

Test and characterization

Twenty-five milliliters of 001 × 7 CERs in H form regenerated by the chemical method and 50 mL of AER regenerated using
the method described above were thoroughly mixed and then loaded into a self-made ion exchange glass column (30 mm Φ, 300 mm height). The breakthrough reaction experiment was performed using tap water as the influent water at a flow rate of \( s = 8 \text{ BV·h}^{-1} \) (bed volume per hour, 1 bed volume = 0.75 L). About 50 mL of effluent water was obtained to test for conductivity. The conductivity of the influent water ranged from 280 \( \mu \text{s/cm} \) to 310 \( \mu \text{s/cm} \), and the breakthrough reaction experiment was terminated when the conductivity reached 300 \( \mu \text{s/cm} \). Unregenerated AERs corresponded to the blank experiment. A schematic of the breakthrough experiment is presented in Figure 2.

In addition, AERs before and after regeneration were dried at 50 °C, and ground by quartz mortar, and then characterized by Fourier-transform infrared (FT-IR) spectrum, respectively, and Mg/Al hydroxides were collected and dried at 105 °C after regeneration for FT-IR spectroscopy.

RESULTS AND DISCUSSION

In this study, the electrical conductivity (EC) breakthrough curve is adopted as a standard to estimate the exchange performance and effect of the resin after regeneration. The EC can indicate the amount of impure ions, including \( \text{CO}_3^{2-}, \text{HCO}_3^{2-}, \text{SO}_4^{2-}, \) and \( \text{Cl}^- \), in the sample. When tap water flows through the resin layer with a large number of exchangeable \( \text{OH}^- \), these \( \text{OH}^- \) can be replaced by the impure ions in the water. Consequently, the resin retains the impure ions, thereby reducing the amount of impure ions in the tap water and markedly decreasing the EC of the effluent water. The EC and volume of the effluent water reflect the regenerative effect of the AERs. Compared with acid–base titration, the proposed technology presents a potentially simple, feasible, practical, and inexpensive method; in this approach, controlling only for human errors is necessary (Shackelford et al. 1999).

Comparison of the regeneration methods

Figure 3 shows the breakthrough curves obtained from three different regeneration techniques. Compared with the blank experiment curve, the curves indicate that the three methods can effectively regenerate fouled AERs. Figure 3(a) shows that, at a terminal point of 300 \( \mu \text{s/cm} \), the volumes of the effluent water tend to increase under the ER, HR, and EHR setups. Figure 3(b) shows that EHR obtained the highest quality of effluent water among the techniques tested, and also that this technique maintained the increased volume of effluent water at reduced conductivity: 0.45 L of effluent water was obtained at a conductivity of less than 2 \( \mu \text{s/cm} \), and 2.4 L of effluent water was obtained at a conductivity of less than 10 \( \mu \text{s/cm} \) for 32 times the volume of the mixed resin bed.

Figure 4 presents a schematic of the Mg/Al HR mechanism of AERs by electric field intensification. Under an electric field, \( \text{H}_2\text{O} \) is electrolyzed, and the cathode and the
anode exhibit the reactions below:

Cathode: $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$ \hspace{1cm} (3)

Anode: $2\text{H}_2\text{O} - 4\text{e}^- \rightarrow \text{O}_2 + 4\text{H}^+$ \hspace{1cm} (4)

After the fouled AERs are drawn into the interior of the electrochemical setup, the resin beads remain around the cathode. The OH$^-$ groups produced on the cathode are displaced by the inorganic anions on the AERs; thus, these OH$^-$ groups are displaced onto the functional groups of the resin. Meanwhile, inorganic anions, such as CO$_3^{2-}$ and HCO$_3^-$, enter the circulating solution. O$_2$ and H$^+$, produced on the anode, pass through the microporous titanium filter electrode under the vacuum pump, and then enter the circulating solution. The continuous export of anode products leads to production of more OH$^-$ groups by the continuous electrolysis of H$_2$O near the cathode; consequently, fouled AERs are continuously regenerated.

After the Mg/Al hydroxides are added into the circulating solution, these hydroxides exhibit drastic turbulence within the electrochemistry setup. Mg(OH)$_2$, Al(OH)$_3$, and H$_2$O are electrolyzed under the electric field to dissociate OH$^-$ groups, and the reaction equations are described as follows:

$$\text{Mg(OH)}_2 \rightarrow \text{Mg}^{2+} + 2\text{OH}^- \hspace{1cm} (5)$$

$$\text{Al(OH)}_3 \rightarrow \text{Al}^{3+} + 3\text{OH}^- \hspace{1cm} (6)$$

$$\text{H}_2\text{O} \rightarrow \text{H}^+ + \text{OH}^- \hspace{1cm} (7)$$

According to enthalpy change ($\Delta H$) of chemical reaction (Haynes 1988; Fu 2005), the calculated results are $\Delta H(5) = -2.36 \text{kJ/mol}$, $\Delta H(6) = 68.74 \text{kJ/mol}$, $\Delta H(7) = 55.83 \text{kJ/mol}$, and the exchanges of energy per mole OH$^-$ are $\Delta H(5) = -1.18 \text{kJ/mol}$ OH$^-$, $\Delta H(6) = 22.91 \text{kJ/mol}$ OH$^-$, $\Delta H(7) = 55.83 \text{kJ/mol}$ OH$^-$. That is, the electrolysis of Mg/Al hydroxides is easier than that of H$_2$O. Thus, OH$^-$ groups first come from electrolysis of Mg/Al hydroxides and second from electrolysis of H$_2$O.

These OH$^-$ groups are displaced with the inorganic anions while in contact with the AERs, which could well recover the ion exchange capacity of the resin. Mg(OH)$_2$, Al(OH)$_3$, Mg$^{2+}$, and Al$^{3+}$ are cycled with the solution, and the flocculent hydroxides are in frequent contact with the AERs in the present setup. This frictional reaction could strip the fouled groups on the resin beads and remove the ‘coat’ of the bead surface. Consequently, the ion exchange...
capacity of the AERs is renewed rapidly. This process is illustrated in Figure 4.

Figure 5 depicts FT-IR spectrums of AERs including fouled resins and resins after ER. Figure 5(a) demonstrates that the peak at 1,383 cm\(^{-1}\) is the antisymmetric stretching vibration band of CO\(_3^2^-\). The peak at 891 cm\(^{-1}\) presents the weaker bending vibration band of CO\(_3^2^-\). The peaks at 1,121 and 614 cm\(^{-1}\) record the vibration bands of SO\(_4^{2-}\). The other peaks record the characteristic peaks of the styrene skeleton, that is, the inorganic anions on the resins are CO\(_3^2^-\) and SO\(_4^{2-}\). Figure 5(b) shows the vibration bands of SO\(_4^{2-}\) at 1,117 and 608 cm\(^{-1}\); however, there are not the characteristic peaks of CO\(_3^2^-\), which demonstrates that the CO\(_3^2^-\) on the resins has been replaced or stripped to enter into the solution under drastic turbulence and frequent friction, and confirms that this regeneration method could remove the CO\(_3^2^-\) groups and restore the exchange capacity of resin.

Figure 6 shows the FT-IR spectrum of Mg/Al double-metal hydroxides after regeneration. The peaks at approximately 3,457 and 1,633 cm\(^{-1}\) are, respectively, attributed to the stretching and bending vibration bands of O–H groups. This observation explains the presence of crystal water in the product after regeneration. The peak at 972 cm\(^{-1}\) characterizes the bending vibrations of the CO\(_3^2^-\) group. The antisymmetric vibrations of CO in the CO\(_3^2^-\) group appear at 1,360 cm\(^{-1}\) (Kloprogge et al. 2004). The peaks below 800 cm\(^{-1}\) are attributed to the lattice vibrations of M–O and O–M–O (M = Mg, Al) groups (Nakato et al. 2000). The presence of CO\(_3^2^-\) in the Mg/Al hydroxides after regeneration was verified. That is, the fouled inorganic anions on the resins have entered into Mg/Al hydroxides. A previous study (Wang et al. 2015) demonstrated that, after reaction, the regenerator was transformed into Mg/Al layered double-metal hydroxides (Mg/ALDHs) under the appropriate temperature, pH value, and reaction time, among other conditions. As the fouled inorganic anions are restrained firmly inside the hydroxides, the transfer of the fouled inorganic anions from the solid phase to the solid phase is realized, and the producing of Mg/ALDHs resulted in the irreversibility of the resin regeneration. Moreover, according to the ‘calcination memory’ function of LDHs (Yoon et al. 2014), the regenerator could be used repeatedly, which further decreases operating costs. This technique clearly differs from traditional chemical regeneration and single electrochemical regeneration.

According to the above characterization and introduction, the mechanism of resin regeneration can be summarized: (1) when Mg/Al hydroxides regenerated the fouled AERs by electric field intensification, the OH\(^-\) were produced through the dissociation of Mg/Al hydroxides and the electrolysis of H\(_2\)O; (2) these OH\(^-\) exhibited a common reaction with the fouled AERs, the CO\(_3^2^-\) groups on the resins were removed or were replaced with the OH\(^-\), the OH\(^-\) were replaced onto the resins, which restored the exchange capacity of resins; (3) the removed CO\(_3^2^-\) groups could enter into the solution and recombine with Mg\(^{2+}\), Al\(^{3+}\), and OH\(^-\) to produce Mg/ALDHs, which significantly realized the irreversibility of the resin regeneration.

Thus, the theoretical analysis and the experimental results were identical. Mg/Al double-metal HR of AERs by electric field intensification may be considered the optimal method among the techniques tested.

**Comparison of curves with different regeneration voltages**

Figure 7 shows the breakthrough curves obtained at 10, 20, and 30 V for 4 h. Figure 7(a) shows that the volumes of effluent water were 3.45, 5.3, and 4.45 L at a conductivity of less
than 300 μs/cm; these volumes are 46, 71, and 59 times, respectively, the volume of the mixed resin bed. Figure 7(b) shows that the volumes of effluent water were 2.9, 4.05, and 3.35 L at a conductivity of less than 10 μs/cm; these values are 39, 54, and 45 times, respectively, the volume of the mixed resin bed. When the volume and quality of the effluent water are considered, 20 V appears to be the optimal voltage to improve regenerative effects.

As voltage increased, the electrolysis degree of Mg/Al hydroxides and H₂O also increased, and more OH⁻ groups were produced; thus, the relatively full regeneration of AERs was achieved. However, as voltage increased, more gas was produced by the oxidation–reduction reaction on the electrode surface. More bubbles were produced and remained on the electrode surface under the limited power, thereby negatively influencing mass transfer in the electrochemical system, blocking the migration of OH⁻, H₂, O₂, and H⁺, and decreasing opportunities for OH⁻ contact with the resin beads. The gas at the anode could not be diffused from the electrochemical system in a timely manner, indirectly affecting the regeneration of AERs. Table 2 shows that power consumption rose as voltage increased. Thus, considering operating costs, 20 V is the optimal voltage for AER regeneration.

Given the above analysis, the power consumption necessary for resin turbulence and solution circulation was lower, that is, 0.381 kWh at 20 V for 4 h. Considering power consumption, the proposed regenerative method is worthy of recommendation and application.

### Comparison of curves with different regeneration times

The breakthrough curves obtained under different regeneration times are shown in Figure 8. Comparison of the volumes of effluent water showed the order V₄ h > V₅ h > V₃ h > V₂ h > V₁ h; these volumes were 71, 47, 41, 37, and 35 times, respectively, the volume of the mixed resin bed.

Figure 9 presents a comparison of the volume of effluent water with varying regeneration times at a conductivity of less than 10 μs/cm. A reaction time of 4 h yielded the largest volume of the effluent water, at 3.85 L, which is 51 times the volume of the mixed resin. Thus, comparison of the quality of the effluent water yielded the order Q₄ h > Q₅ h > Q₃ h > Q₂ h > Q₁ h.

More OH⁻ groups were produced by electrolysis with increasing time, resulting in a gradual increase in temperature within the electrochemical system. Heat was produced by mechanical heating within the instrument during the vacuum pump operation. The increase in temperature facilitated H₂O electrolysis as well as polymerization, dissociation, and recombination of Mg/Al hydroxides (Xu et al. 2014). However, under a specific condition.
increase in time, H2O electrolysis and mass transfer within the electrochemical system weakened because of adsorption of contaminants on the anode surface and attachment of Mg/Al hydroxides within the cathode, which could directly affect the regeneration of AERs. Extending the reaction time did not necessarily exert a positive regenerative effect.

Therefore, on the basis of the experimental results, 4 h was the optimal regeneration time to obtain the largest volume and highest quality of effluent water.

### Breakthrough curves with different dosages of Mg/Al hydroxides

Breakthrough curves obtained under different Mg/Al hydroxide dosages at a Mg/Al molar ratio of 3 are shown in Figure 10. The figure does not indicate that the volume of the effluent water increased gradually with increasing hydroxide dosage. Increased dosages allowed Mg/Al hydroxides to adsorb into the surface of the anode easily. The pores of the titanium filter electrode were blocked, thereby inhibiting the passing of the anode product and delaying the running speed of the solution. The cycling speed and cycling amount of the solution were also reduced, indirectly influencing the regenerative effect of the resin. When the Mg/Al hydroxide dosages were reduced, the released OH⁻ decreased accordingly, inevitably weakening the regeneration of the resins. Consequently, the dosages of the Mg/Al hydroxides must be controlled carefully. The optimal dosages of Mg/Al hydroxides were determined to be 0.09 and 0.03 mol, respectively.

### Test of maximum regenerative capacity of AERs

The above EC breakthrough curves could indirectly respond to the exchange capacity of resins, and to more accurately reflect the exchange capacity of the resins, the maximum regenerative capacity of the unregenerated and the regenerated resins under the optimized conditions (20 V voltage,
4 h of reaction time, and Mg/Al hydroxide dosages of 0.09 and 0.03 mol, respectively) were tested by the national standard of the People’s Republic of China (GB5760-2000). The maximum regenerative capacity of resin shows in per gram AERs the total number of active groups which could react with excess monobasic strong acid, expressed in mmol/g.

The testing process was as follows: the resins reacted with excessive HCl standard titration solution, and then NaOH standard titration solution underwent back titration with excessive HCl solution. Finally, to calculate the dosage of HCl standard titration solution reacting with the resins, the maximum regenerative capacity of AERs was obtained according to formula (8):

$$Q_1 = \frac{100c_1 - 4c_2 \cdot V_1}{W_1(1 - X)}$$

where $Q_1$ is maximum regenerative capacity of AERs in hydroxylic form, mmol/g; 100 is the amount of HCl standard titration solution, mL; $c_1$ is the concentration of HCl standard titration solution, mol/L; $c_2$ is the concentration of NaOH standard titration solution, mol/L; $V_1$ is the volume of NaOH standard titration solution, mL; $W_1$ is the weight of resins, g; and $X$ is the water content of AERs in hydroxylic form, %; refer to (GB5759-2000).

The results are shown in Tables 3 and 4.

Table 3 shows that the maximum regenerative capacity of AERs before and after regeneration is 1.4341 and 2.0231 mmol/g, respectively, and the increasing rate of maximum regenerative capacity is 41.07%. These results were consistent with those of the EC breakthrough curve results mentioned above. Moreover, specific data could also identify that this regenerative technique could restore the exchange capacity of the resins, and was quite effective and feasible.

**Changes in conductivity, pH value, and electric current during regeneration**

During conductivity measurements, the pH and electric current of the circulating solution during regeneration can directly indicate the reaction state and regenerative degree of the resins.

The conductivity, pH, and electric current during regeneration at 20 V for 5 h are shown in Figure 11. As the reaction time increased, the conductivity of the circulating solution increased gradually, which could be related to the diffusion of Mg/Al hydroxide sols. Mg/Al hydroxides slowly entered the circulating solution from the storage container (as shown in Figure 1) and gradually reacted with the AERs, thereby inducing a steady increase in the conductivity of the solution. The stripped fouled anions from the interior or the surface of the resin beads slowly entered the circulation solution, exerting an auxiliary intensive action to enhance conductivity. When the conductivity reached 200 μS/cm, regeneration was basically completed.

Figure 11 shows that, following the process of regeneration, the pH of the circulation solution decreased from 11 to approximately 7.5 and was maintained at about 7.5 for the next 3 h. This change was attributed to the fact that the $O_2$, $H^+$, and so on produced on the anode under the action of the vacuum pump could pass through the microporous titanium filter electrode to enter the circulation...
solution. O₂ could disperse into the air, and the steady increase in H⁺ resulted in continuous reductions in pH. Thus, when the pH value was reduced to around 7.5, the reaction tended to stabilize. In addition, compared with the traditional alkali liquor regenerative method that produces a great deal of saline waste water, about 10–20% of the treated water (Ghasemipanah 2012; Luo et al. 2013), in this technique the neutral regenerative solution for about 16 L could be recycled, which could realize zero release. In some cases, the recycling and structural performances of regenerant make the regenerative process environmentally friendly and cost-effective.

As the reaction time increased, the electric consumption of the electrochemical equipment also gradually increased. This increase in electric current indicates that migratory cations and anions within the equipment as well as the amount of ions produced by electrolysis increased. After the Mg/Al hydroxides entered the circulation system, the hydroxides dispersed gradually and uniformly into the circulation solution, providing more migratory ions that further magnified the electric current. Thus, increased electric currents may reflect the regenerative degree of the AERs.

CONCLUSIONS

In this study, the experimental results confirmed that Mg/Al double-metal HR of AERs by electric field intensification is the optimal method among the techniques tested. The optimal regenerative conditions for 100 mL AERs with a 201 × 7 strong basic styrene skeleton and inorganic anion contamination were as follows: 20 V voltage, 4 h of reaction time, and Mg/Al hydroxide dosages of 0.09 and 0.03 mol, respectively. The increasing rate of maximum regenerative capacity was 41.07%. During regeneration and the OH⁻ produced by Mg/Al hydroxides, H₂O electrolysis exhibited a common reaction with the fouled AERs, significantly reinforcing the regenerative effect of the AERs. The regenerative mechanism was also presented by the FT-IR spectrum of AERs and Mg/Al hydroxides. The regenerative process was analyzed in terms of conductivity, pH value, and electric current. In the regeneration technique, the power consumption was relatively low, no acid and alkali waste liquids were produced, resin rinsing was not required, and the Mg/Al hydroxides obtained after regeneration could be recycled by calcination. Thus, this method is a cost-effective and environmentally friendly technique to recover AERs. Considering its many benefits, the proposed technique appears to be suitable for application in the field of water treatment.

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