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The adsorption behavior and mechanistic investigation of Cr(VI) ions removal by poly(2-(dimethylamino)ethyl methacrylate)/poly(ethyleneimine) gels

ZHENGBO HOU, WEIXIA ZHU, HANG SONG, PENGFEI CHEN and SHUN YAO*

School of Chemical Engineering, Sichuan University, Chengdu, 610065, China

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Abstract: The composite hydrogels based on 2-(dimethylamino)ethyl methacrylate (DMAEMA) and polyethyleneimine (PEI) were prepared by amino radical polymerization and confirmed by Fourier transform infrared (FTIR) spectroscopy and elemental analysis. Then adsorption behavior and mechanism of Cr(VI) ions adsorption on the obtained materials were investigated by scanning electron microscopy, zeta potential determination and thermogravimetric analysis, *etc*. The adsorption process was found to follow pseudo-second order kinetics and the Langmuir model, and the maximum adsorption capacity of Cr(VI) ions reached 122.8 mg g^{-1}. X-ray photoelectron spectroscopy (XPS) and pH analysis revealed that the Cr(VI) ions were adsorbed into the gels through the electrostatic interaction mechanism, and SO_4^{2-} in the solution had a great effect on the adsorption process. In addition, a high pH and ionic strength could reduce the uptakes of the adsorbate, which could be used for desorption of Cr(VI) ions from the gels.

Keywords: 2-(dimethylamino)ethyl methacrylate; polyethyleneimine; adsorption; Cr(VI); polymerization.

INTRODUCTION

At present, many techniques, such as chemical reduction, adsorption, electrolysis, ion exchange, precipitation *etc*., are employed to remove Cr(VI) ions from wastewater.[1–3] Cr(VI) ions are more toxic than Cr(III).[4] Among the reported traditional techniques, adsorption is an effective method due to the adventages of high selectivity, no secondary pollution, easy operation and the possibility of adsorbent recycling. Various adsorbents have been used to remove Cr(VI), such as macroporous 1,2-ethylenediamine-aminated polystyrene particles.[5] crosslinked cassava residue xanthate,[6] functionalized ordered mesoporous carbon,[7] hard walnut shell,[8] *β*-FeOOH-coated sand,[9] nitrogen-enriched activated

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* Corresponding author. E-mail: cusack@scu.edu.cn

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carbon from waste medium density fiberboard,[10] a chitosan-coated fly ash composite,[11] iron(III)-impregnated sorbent prepared from sugarcane bagasse,[12] *etc*. Their maximum adsorption capacities were 100.06, 37.76, 68.21, 80.24, 0.060–0.076, 89.21, 33.00 and 13.72 mg g^{-1}, respectively. At present, the exploration for new practical, economic and efficient adsorbents for the removal of Cr(VI) ions is still meaningful and necessary.

In recent years, hydrogels prepared from 2-(dimethylamino)ethyl methacrylate (DMAEMA) and its co-polymers have attracted much interest due to their pH and thermal sensitivity.[13,14] A large number of research reports were concerned with more special environment sensitivities and their applications for water treatment.[15–17] Poly-DMAEMA exhibited a high adsorption capacity (70 mg g^{-1}) for Cr(VI).[18,19] Polyethyleneimine (PEI) is a water-soluble polyamine with many nitrogen atoms of amino groups on its macromolecular chains, which could interact effectively with some kinds of pollutants. Therefore, the copolymerization of PDMAEMA and PEI was expected to provide a material with a high adsorption capacity for the removal of Cr(VI) ions from aqueous solution.

In this study, PEI macromolecules were grafted onto PDMAEMA *via* free radical polymerization on the amine nitrogen atoms, yielding PEI/PDMAEMA for the first time as a novel cationic composite material for the adsorption of anions. The adsorption properties of Cr(VI) ions on the PEI/PDMAEMA were studied thoroughly. It was expected that this PEI/PDMAEMA material would possess satisfactory adsorption capacity and rate for Cr(VI) ions in water.

EXPERIMENTAL

Materials

2-(Dimethylamino)ethyl methacrylate (DMAEMA) monomer, *N*,*N*′-methylenebisacrylamide (MBAA) cross-linker, and azobisisobutyronitrile (AIBN) initiator were purchased from Puguang Industrial Co., Ltd. (each of purity >99 % , Shanghai, China). Branched polyethyleneimine (PEI) ($\bar{M}_w$ = 1800 g mol^{-1}, 25 % aqueous solution, the content of primary, secondary and tertiary amino groups were 35, 35 and 30 %, respectively) was obtained from Mengde Electroplate Chemistry Co. (specific electro-plating class, Jiangsu, China). K_2CrO_4 was provided by Jingqiu Chemistry Factory (AR, Beijing, China).

Preparation of the adsorbents

The polymerization procedures for DMAEMA monomer and MBAA cross-linker were studied in a previous study.[19] For each polymerization, first, 3.144 g DMAEMA, 0.154 g MBAA, and 0.050 g AIBN were dissolved in 3 mL of ethanol solution and the PEI solution was diluted with distilled water to prepare a solution with the mass concentration (0–5 wt. %). Then, the ethanolic mixture was added into 18 mL PEI solution of different concentrations and stirred under a nitrogen atmosphere for 10 min. Afterwards the solutions were immediately poured into tubes with 6 mm inner diameter, which were sealed and submerged in thermostatic water bath for 3 h at different temperatures. Finally, the PEI/PDMAEMA gels were rapidly cooled to room temperature and cut into 3-mm thick slices for further use. The composite materials prepared with 0, 3 and 5 wt. % PEI solution were marked as ED 0, ED 3 and ED 5, respectively.

The amount of PEI in the adsorbent (graft yield, *GY*) was determined by element analysis. According to the content of elements, *GY* could be calculated as follows:

$$GY(\%) = \frac{W_{\mathrm{PEI}}}{W_{\mathrm{PDMAEMA}}}\times 100 \tag{1}$$

where W_{PEI} and W_{PDMAEMA} are the PEI and PDMAEMA weight percentage in the PEI/ /PDMAEMA material, respectively, which were calculated from the results of the element analysis.

Characterization of the PDMAEMA and PEI/PDMAEMA

The FTIR spectra of PDMAEMA and PEI/PDMAEMA were recorded on Spectrum One FTIR spectrometer (Perkin–Elmer, USA) as KBr discs. The zeta potential analysis was performed using a PALS Zeta Potential Analyzer, version 3.43 (Brookhaven Instruments, USA). Elemental analyses were accomplished with 2400 Series II CHNS/O elemental analyzer (PerkinElmer, USA). The DTG curves were obtained using a FRC/T-2 thermal analyzer (Optical Instruments Factory, Beijing, China) at a heating rate of 10 °C min^{-1} under a nitrogen atmosphere. The morphology of the dried composite materials after drying under vacuum at 50 °C for 24 h was observed using a JEM-100CX-II scanning electron microscope (SEM). (JEOL, Japan). X-ray photoelectron spectroscopy (XPS) data were obtained with an ESCALab220i-XL electron spectrometer (VG Scientific, USA) using 300 W AlK$_\alpha$ radiation. To compensate for surface charge effects, the binding energies were calibrated using the C1s hydrocarbon peak at 284.8 eV.

The hydrogels were immersed in water to reach a swollen equilibrium at 40 °C. Afterwards, they were withdrawn and weighed after the removal of excess surface water. Equilibrium Swelling Ratio (*ESR*) is the moisture content to dry weight of hydrogel ratio:

$$ESR = \frac{W_{\mathrm{s}} - W_{\mathrm{d}}}{W_{\mathrm{d}}} \tag{2}$$

where W_{s} is the weight of the swollen gel at the desired time and W_{d} is the weight of the dried gel.

Adsorption of Cr(VI) ions

A certain amount of K_2CrO_4 was dissolved in redistilled water to obtain the stock solution. The concentrations of Cr(VI) were determined by TU1810SPC UV–Vis spectrophotometer (Puxitongyong Instrument Co., Ltd., China) at 540 nm. For each adsorption experiment, the stock solution was diluted to desired concentration (c_0, 25–225 mg L^{-1}), and then the adsorbents were immersed into the conical flasks containing the diluted solution. Finally, the conical flasks were placed in a shaking bed at different temperatures for desired time, and the concentration in supernatant was determined as c_t. In addition, the solution pH was adjusted by 1 mol L^{-1} HCl or 1 mol L^{-1} NaOH and monitored by a digital pH meter (Yulong Instrument Co., Ltd., China).The adsorption amount of Cr(VI) (Q, mg g^{-1}) was calculated according to the following equation:

$$Q = \frac{V(c_0 - c_t)}{W_{\mathrm{PEI/PDMAEMA}}} \tag{3}$$

where V (mL) and $W_{\text{PEI/PDMAEMA}}$ (g) stand for the solution volume and the mass of the adsorbent, respectively.

Desorption of Cr(VI) ions

Firstly, the sorbents were immersed in 150 mg L^{-1} of Cr(VI) solution at pH 2.0 for 4 h to reach equilibrium, respectively. The adsorption amount (Q_a, mg g^{-1}) of Cr(VI) ions, was calculated by Eq. (3). Then the sorbents were filtered and soaked in 10 mL of 0.1 mol L^{-1} NaOH solution for 24 h at room temperature. Finally, the concentration of Cr(VI) ions in the eluent was determined, and the amount of desorption was denoted by Q_d (mg g^{-1}). The desorption ratio was defined by the following equation:

$$\text{Desorption ratio (\%)} = \frac{Q_d}{Q_a} \times 100 \qquad (4)$$

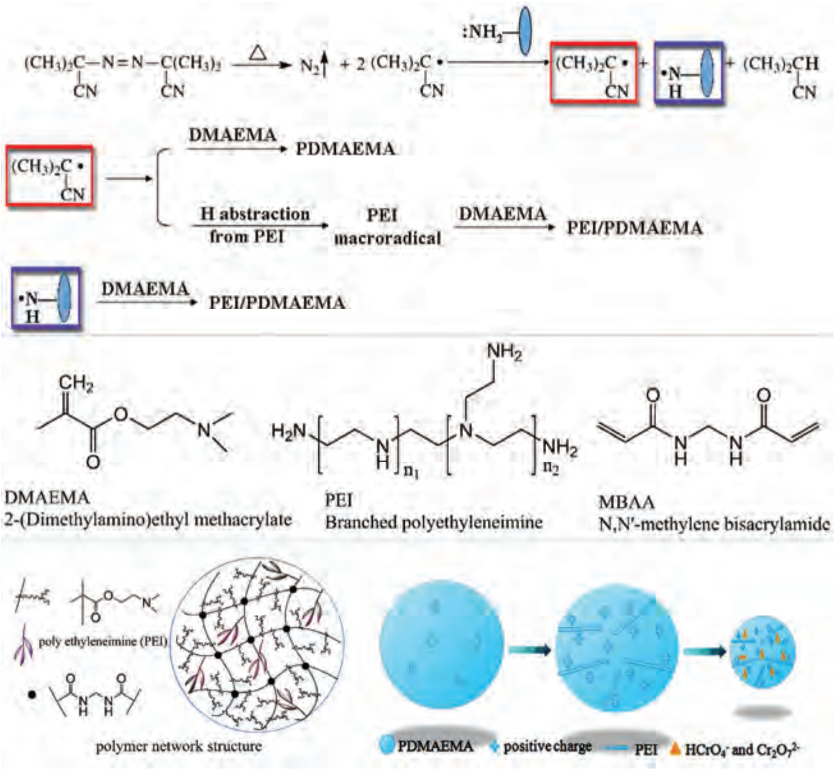
RESULTS AND DISCUSSION

Preparation process and characterization of PEI/PDMAEMA

As a very popular azo-initiator in polymerization processes, azobisisobutyronitrile (AIBN) can easily produce nitrogen gas and radicals through splitting reaction. Polyethyleneimine (PEI) possesses many free amino groups. When they interact with the radicals of the AIBN initiator, the amino group will lose a proton. As the result, a nitrogen radical ($N^{\bullet}$) together with 2-cyano-2-propyl radical ($C^{\bullet}$) could be obtained. Then, the former ($N^{\bullet}$) could initiate the copolymerization of DMAEMA to form PEI/PDMAEMA. The role of amine in vinyl radical polymerizations was summarized and analyzed in a previous study.[20] In addition, the latter ($C^{\bullet}$) could either produce the polymerization among the monomer or abstract a hydrogen atom from the PEI, resulting in the copolymerization of DMAEMA and PEI. The related copolymerization process is shown in Scheme 1.

The ultrasound-assisted (at room temperature) and the Soxhlet extraction methods with 95 % ethanol were first used to verify the copolymerization of PEI on the polymer network. There was no or negligible residual remains in the extracted liquid after the removal of solvent under vacuum. The results indicated that PEI had been successfully grafted onto the network and the copolymerization product was stable. Furthermore, the formation of ED 0 and ED 5 could be further proved by FTIR spectroscopy according to an analysis similar to that in previous reports.[21–24] All of the IR spectra are shown in Fig. 1.

Moreover, zeta potential analysis was used to characterize the PEI//PDMAEMA products. The zeta potential of ED 0 was only +7.25 mV, but for ED 5, it became +20 mV in pH 2 hydrochloric acid buffer solution. This could be interpreted as proof of the incorporation of PEI, which contains many amino functional groups. In order to analyze the content of nitrogen before and after introduction of PEI, the ED 0, ED 3 and ED 5 materials were characterized by elemental analysis (Table I). Compared with ED 0 and ED 3, ED 5 had a higher content of nitrogen. According to elemental analysis, the amount of PEI in the ED 5 was calculated to be 5.93 %.



Scheme 1. Copolymerization process of PEI/PDMAEMA gels and adsorption of Cr(VI).

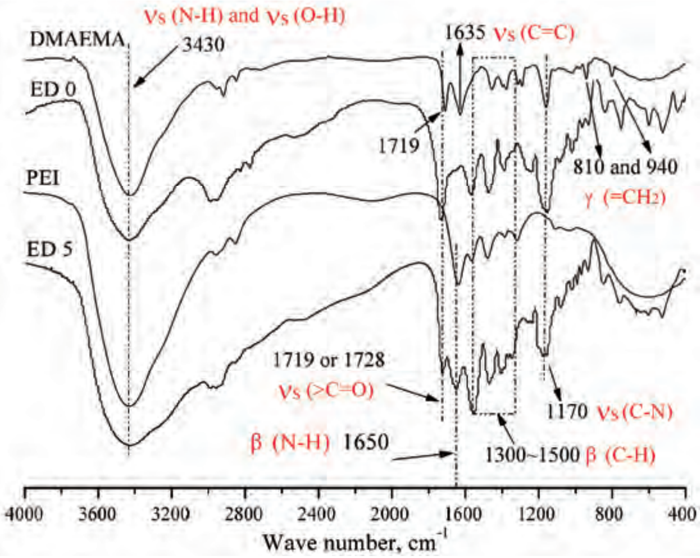


Fig. 1. FTIR spectra of PEI, DMAEMA, PEI/PDMAEMA (ED 5) and PDMAEMA (ED 0).

TABLE I. Elemental analysis (%) of ED 0, ED 3 and ED 5

Material	Element				GY_{PEI} / %
	C	H	N	O	
ED 0	58.50	13.22	6.81	21.47	–
ED 3	58.67	12.01	8.11	21.21	3.76
ED 5	58.60	10.08	9.32	22.00	5.93

The thermal stability of the PEI, ED 0 and ED 5 gels were examined by thermal analysis (Fig. 2). The removal of physically adsorbed and interlayer water occurred up to 150 °C, and the raw PEI sample lost its 75 % weight in this temperature range. In the second stage, a significant weight loss of 44.68 % could be attributed to the decomposition of the functional amino-groups on the composite material when the temperature ascended to 300 °C. As shown in the differential thermogravimetric (DTG) curves, the rate of mass loss reached its maximum at 281 °C for ED 0, but was postponed by 20 °C after incorporation of PEI. In the last stage, a smaller mass loss of 14.83 % in the 300–400 °C range was associated with degradation of the carbon skeletons, and the fastest decomposition rate appeared at 413 °C. These results implied that the ED 5 gel was successfully prepared and ED 5 could be applied in higher temperature system.

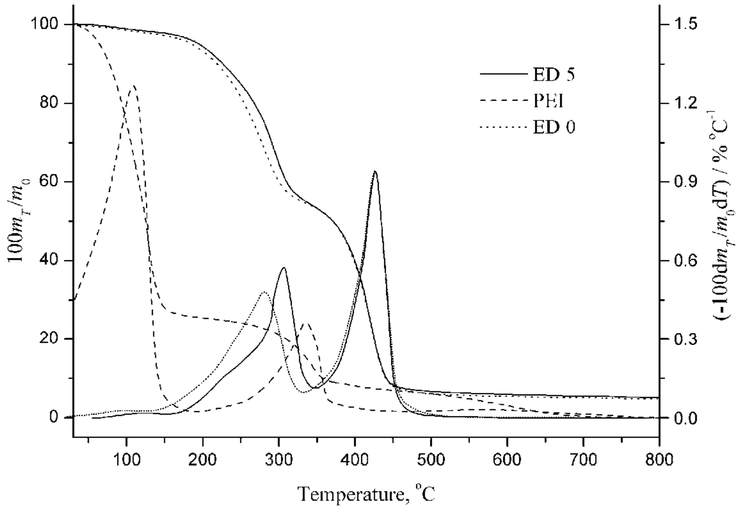


Fig. 2. Thermogravimetric and differential thermogravimetric curves of PEI, ED 0 and ED 5.

Equilibrium swelling ratios (ESR) of PEI/PDMAEMA

The swelling behavior of the hydrogels in water at different temperatures is shown in Fig. 3. As is clearly shown, the ESR of ED 0 and the ED 5 gels decreased with increasing temperature and exhibited a marked inflexion when the temperature reached the special critical point, which is consistent with the lower critical solution temperature[25–27] (LCST: around 40 °C and 65 °C for ED 0 and ED 5, respectively). Figure 3 also shown the ESR of ED 5 immersed in buffer solution as a function of pH value. The gel in the buffer solution with the low pH value presented higher swelling ratios than those of the gel in the alkaline solution. The results could be explained by the following reason: the free electron pair of the amino group conjugated with the carboxyl in the DMAEMA units when the gel was immersed in water. However, this coordination was severely weakened in the acidic solution because of protonation of the tertiary amino groups.[27]

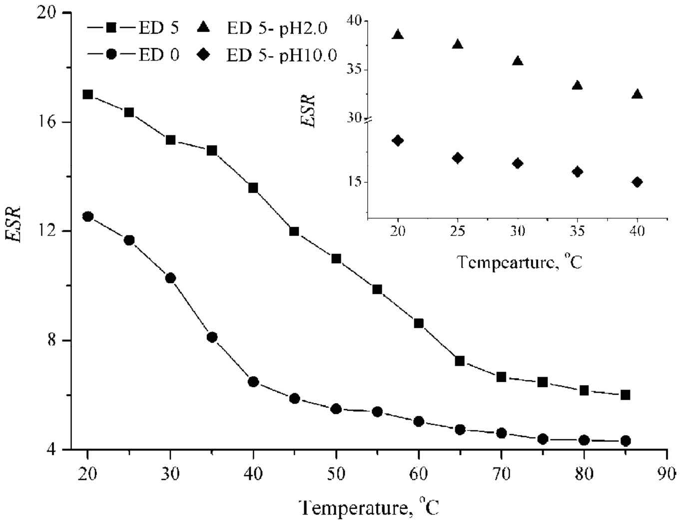


Fig. 3. Equilibrium swelling ratios of ED 0 and ED 5 gels in purified water and ED 5 in acid or alkali solution at different temperatures.

Adsorption kinetics of Cr(VI) ions

Adsorption duration is an important factor affecting the adsorption process and amount. The optimal duration of adsorption was investigated, and the results (Fig. S-1 of the Supplementary material to this paper) showed that the introduction of PEI onto PDMAEMA gels had a significant effect on the adsorption behavior of Cr(VI). When the concentration of PEI was increased to 5 %, the amount of adsorbed Cr(VI) ions increased to 122.8 mg g^{-1} and the adsorption rate was obviously improved, *e.g.*, the adsorption by ED 5 reached complete saturation after 120 min, but for ED 0, 180 min were needed. A high adsorption rate is desirable to provide for a short contact time between the metal solution and the adsorbent in an actual process.[28] Furthermore, the influence of temperature in the preparation process could be ascribed to a change in the degree of crosslinking. The higher the reaction temperature was, the faster was the reaction rate, and the denser was the degree of crosslinking in the network. As the result, the inflexibility of polymer became stronger and the elasticity became weaker. It was very difficult for Cr(VI) anions to be adsorbed by the internal active site with a too high degree of crosslinking.

The kinetic model provides information regarding the mechanism and thus the adsorption data were correlated with the pseudo-first order kinetic model and pseudo-second order kinetic model.[29]

The adsorption kinetic parameters are summarized in Table II. It was found that the theoretical $Q_{e,cal}$ values for the adsorbate were very close to the experimental Q_{eq} values in the case of the pseudo-second order kinetics. Furthermore, all the linear fitting coefficients (R^2) of the pseudo-second order kinetics were above 0.99, which were slightly higher than were those of the pseudo-first order kinetics. Thus, the pseudo-second order equation fitted well with the experimental data and could describe the adsorbent behavior well.

TABLE II. The adsorption kinetic parameters of Cr(VI) ions onto the gels; $Q_{e,exp}$: the equilibrium adsorption amount of Cr(VI) (experimental data); k_1: the adsorption rate constant for the pseudo-first order model; $Q_{e,cal}$: the equilibrium adsorption amount of Cr(VI) (calculated data); k_2: the adsorption rate constant for the pseudo-second order model

Sample	$Q_{e,exp}$ mg g^{-1}	Pseudo-first order model			Pseudo-second order model		
		$k_1\times10^{-3}$ min^{-1}	$Q_{e,cal}$ mg g^{-1}	R^2	$k_2\times10^{-3}$ g mg^{-1}	$Q_{e,cal}$ mg g^{-1}	R^2
ED 0	73.17	16.31	71.30	0.9508	0. 2929	81.94	0.9932
ED 3	95.34	22.98	87.91	0.9637	0.4276	102.1	0.9974
ED 5	122.8	25.42	88.12	0.9643	0.6052	128.0	0.9991
75 °C	91.86	29.75	116.3	0.8881	0.4094	99.41	0.9967
85 °C	122.8	25.37	88.12	0.9643	0.6047	128.0	0.9991
95 °C	85.03	15.59	68.44	0.9867	0.3897	92.25	0.9982

Adsorption isotherm of Cr(VI) ions

Adsorption isotherm is one of the important parameters for understanding the adsorption behavior and mechanism. The adsorption equilibrium curves are shown in Fig. S-2 of the Supplementary material, and the Langmuir and Freundlich isotherm models were used to fit the equilibrium data.[30–33]

As shown in Table III, the values of $Q_{e,cal}$ derived from the Langmuir model increased with increasing temperature up to 40 °C but decreased with further increasing of the temperature. This could be explained as follows: the elevated temperature enhanced the deprotonation of amino-groups and resulted in a weaker interaction between the amino groups and Cr(VI) ions.[16] In addition, from the comparison of R^2, R_L and k values, it was found that the Langmuir model could fit much better with the experiment data. Overall speaking, the

Langmuir isotherm gave a better fit to the experimental data than the Freundlich isotherm. The results indicated insights on the monolayer coverage of PEI/ /PDMAEMA composite and that there were no side interactions among the adsorbates. Furthermore, the site-specific interactions took place between the binding sites and anions, and the adsorbent surface was homogeneous.

TABLE III. The adsorption isotherms parameters of Cr(VI) ions onto the ED 5; K_L: the constant of the Langmuir isotherm; R_L: the separation factor of Langmuir isotherm (favorable ($0 < R_L < 1$), unfavorable ($R_L > 1$), linear relationship ($R_L = 1$) and irreversible ($R_L = 0$)[30-32]); K_F: the constant of the Freundlich isotherm; k: the slope of Freundlich isotherm model (Langmuir isotherm ($k < 1$), Freundlich isotherm ($k > 1$)[32-34])

T / °C	Langmuir model				Freundlich model		
	K_L / 10^2 L mg^{-1}	$Q_{e,cal}$ / mg g^{-1}	R^2	R_L	K_F / mg g^{-1}	k	R^2
30	2.719	146.2	0.9915	0.4238–0.1379	11.23	0.4980	0.9802
40	5.366	172.7	0.9879	0.2715–0.0749	19.41	0.4771	0.8967
50	3.745	159.0	0.9943	0.3481–0.1040	15.36	0.4755	0.9764
60	3.063	153.1	0.9981	0.3950–0.1243	12.12	0.5035	0.9718

Effect of initial pH value on the adsorption process

The pH value influences the distribution of Cr(VI) ions species, Fig. 4 (main forms: $H_2Cr_2O_7$ (pH < 1), $HCrO_4^-$ and $Cr_2O_7^{2-}$ (1 < pH < 6) and CrO_4^{2-} (pH > > 6)). For PEI/PDMAEMA, the pH value affects the protonation and deprotonation of amino groups, which are the active adsorption sites for anions. The maximum amount of Cr(VI) ions adsorption onto ED 5 and ED 0 were both obtained at pH 2.0. With increasing pH values, the interaction between anions and amine groups weakened because of the deprotonation of the amino groups and the competition of OH^-. However, when the pH value was below 2.0, the uptake of

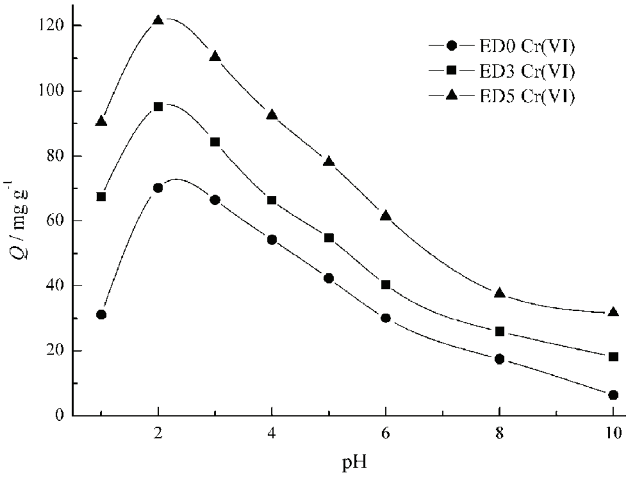


Fig. 4. The effects of pH on the adsorption of Cr(VI) ions onto the gels at 40 °C.

Cr(VI) ions decreased because the Cr(VI) ions converted into $H_2Cr_2O_7$, which unfavorably interacted with the protonated amine groups. Furthermore, when the pH value was 10.0, the Cr(VI) uptake was still up to 32 mg g^{-1} onto the ED 5. It could be concluded that the adsorption amount reached maximum values around a pH value of 2.0, and the working pH range of the composite adsorbent for Cr(VI) ions was obviously improved due to the introduction of PEI.

Effects of ionic strength and species on the adsorption process

The results are shown in Fig. S-3 of the Supplementary material. The adsorption capacities of the gels remarkably decreased with increasing concentration of NaCl because of the competition between Cl^- and the anionic adsorbents. The effect of ionic species could be divided into two groups: cationic group (NaCl, KCl and NH_4Cl) and anionic group (NaCl, $NaNO_3$ and Na_2SO_4). The results showed that the effects of ions (Na^+, K^+, NH_4^+, Cl^- and NO_3^-) on the adsorption process were not obvious. Comparatively speaking, the SO_4^{2-} had a great effect on the adsorption process. This could be summarized as the competition between Cr(VI) and SO_4^{2-}.

Morphology and XPS analysis

Figure 5 shows the SEM images of ED 0, ED 5 and ED 5 after adsorption of Cr(VI). These samples were coated with a thin layer of gold and examined by

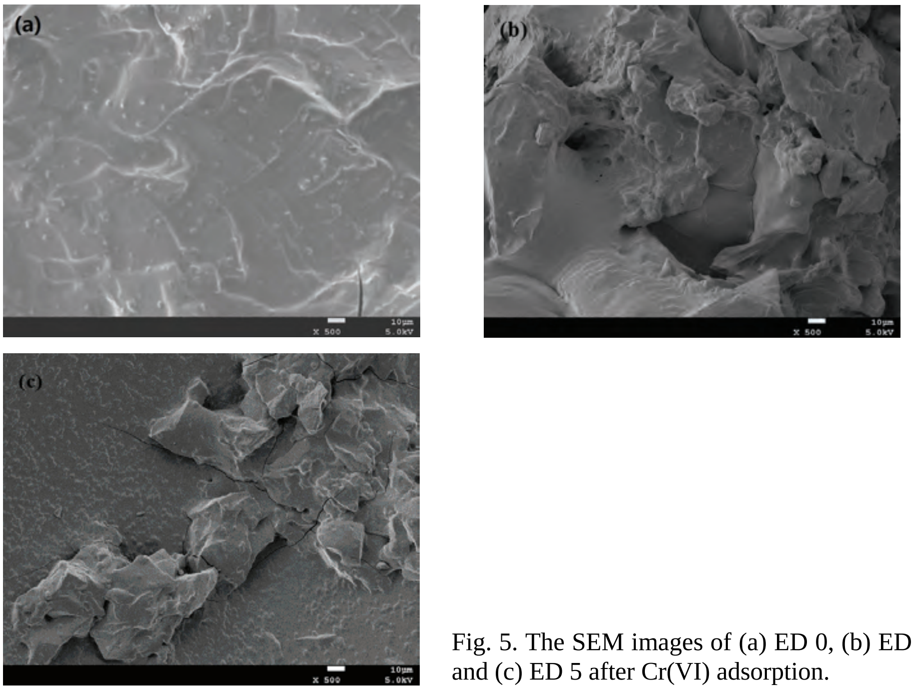
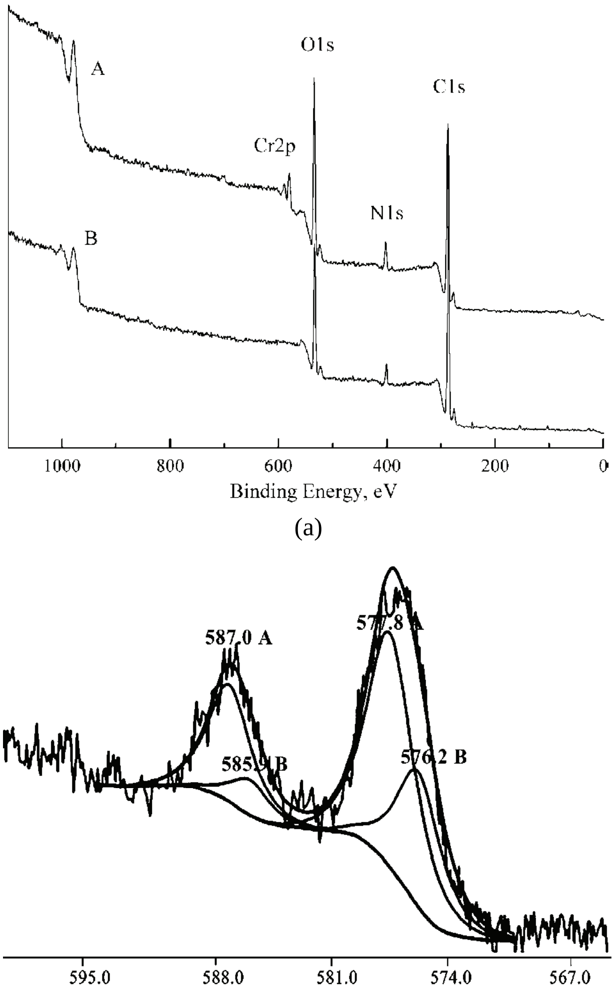


Fig. 5. The SEM images of (a) ED 0, (b) ED 5 and (c) ED 5 after Cr(VI) adsorption.

SEM. After the introduction of PEI on the polymer, there were no significant changes in the morphology of the gels. However, clearly ragged topographies appeared after Cr(VI) ions adsorption, which was relevant to the formation of bubbles during the adsorption process.

The XPS spectra of the ED 5 composite material before and after Cr(VI) adsorption are shown in Fig. 6a. Before adsorption, only the peaks at the binding energies of *ca*. 284.8, 399.5 and 532.4 eV, corresponding to C, N and O, res-



(a)

(b)

Fig. 6. a) The XPS spectra of ED 5 composite material before (A) and after (B) Cr(VI) adsorption; b) the results of a meticulous XPS analysis of the ED 5 composite material for (A) $Cr_2O_7^{2-}$ and (B) $HCrO_4^-$ adsorption.

pectively, could be found in the XPS spectrum of ED 5. After adsorption, new significant bands corresponding to Cr(VI) appeared at binding energy of *ca*. 577.2 and 586.8 eV. The result confirmed that Cr(VI) had been adsorbed onto ED 5. Furthermore, a meticulous XPS analysis was performed using fitting software and the results were presented in Fig. 6b. The main peak of *ca*. 277.5 eV was made up of 577.8 and 576.2 eV peaks, which indicated that the forms of the adsorbed Cr(VI) ions were $HCrO_4^-$ and $Cr_2O_7^{2-}$.[35] This conclusion was in accord with the fact that $HCrO_4^-$ and $Cr_2O_7^{2-}$ exist mainly in the pH range of 1.0–6.0.

Desorption of Cr(VI) ions

According to repeated experiments, the pH value of the solution could obviously affect the interaction between anionic adsorbates and the amine groups in the composite materials. Thus, 0.1 mol L^{-1} NaOH solution was chosen for the desorption process. The results showed 96.3 % of Cr(VI) ions were eluted from ED 5 by the alkali liquor, far higher than the 56.8 % by distilled water. Then, the ED 5 was washed to neutral with distilled water and reused to adsorb Cr(VI) ions. The adsorption capacity remained high at 108.5 mg g^{-1} after being recycled five times. There was no significant reduction in its adsorption efficiency. The results also revealed that the PEI/PDMAEMA gels were stable under these experimental conditions.

CONCLUSIONS

Using the amino radical polymerization technology, the composite material PEI/PDMAEMA was conveniently fabricated, and the complex grafting process was avoided. The composite material was characterized by FTIR spectroscopy, elemental analysis, thermogravimetric analysis and zeta potential analysis. The equilibrium adsorption amount of Cr(VI) on ED 5 was 122.8 mg g^{-1}. The results of the influence of temperature, pH and XPS analysis showed that the adsorption mechanism was electrostatic interaction, and the forms of Cr(VI) ions adsorbed onto the ED 5 at pH 2 were $HCrO_4^-$ and $Cr_2O_7^{2-}$. The desorption ratio of Cr(VI) ions could be 96.3% using 0.1 mol L^{-1} NaOH solution as the eluent and the composite material PEI/PDMAEMA showed an excellent recyclability efficiency.

SUPPLEMENTARY MATERIAL

Additional Cr(VI) adsorption data are available electronically from http:// //www.shd.org.rs/ JSCS/, or from the corresponding author on request.

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ИЗВОД

ИСПИТИВАЊЕ МЕХНИЗМА АДСОРПЦИЈЕ ПРИ УКЛАЊАЊУ Cr(VI) ЈОНА ГЕЛОВИМА ПОЛИ(2-(ДИМЕТИЛАМИНО)ЕТИЛ-МЕТАКРИЛАТ)/ПОЛИ(ЕТИЛЕНИМИН)

ZHENGBO HOU, WEIXIA ZHU, HANG SONG, PENGFEI CHEN и SHUN YAO

School of Chemical Engineering, Sichuan University, Chengdu, 610065, China

Композитни хидрогелови базирани на 2-(диметиламино)етил-метакрилату (DMAEMA) и полиетиленимину (PEI) су добијени полимеризацијом амино радикала, што је потврђено инфрацрвеном спектроскопијом са Фуријеовом трансформацијом (FTIR) и елементалном анализом. Мехнизам адсорпције Cr(VI) на добијеним материјалима је испитиван скенирајућом електронском микроскопијом, одређивањем зета потенцијала и термогравиметријском анализом. Нађено је да процес адсорпције прати кинетику псеудо-другог реда и Лангмиров модел, као и да је максимални адсорпциони капацитет Cr(VI) јона 122,8 mg g^{-1}. Анализом фотоелектронском спектроскопијом X-зрачења (XPS) и pH мерењима је показано да су Cr(VI) адсорбовани на геловима електростатичким интеракцијама, и да SO_4^{2-} у раствору има значајан утицај на процес адсорпције. Уз то, високе вредности pH и јонске јачине погодују редукцији адсорбованих Cr(VI) јона, што се може искористити приликом њихове десорпције са гелова.

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REFERENCES

1. L. Zhao, J. Sun, Y. H. Zhao, L. Xu, M. L. Zhai, *Chem. Eng. J.* **170** (2011) 162
2. V. Pascal, D. Laetitia, S. Joël, S. Marc, P. Serge, *Appl. Surf. Sci.* **253** (2007) 3263
3. K. J. Cronje, K. Chetty, M. Carsky, J. N. Sahu, B. C. Meikap, *Desalination* **275** (2011) 276
4. V. Janaki, K. Vijayaraghavan, A. K. Ramasamy, B. T. Oh, K. J. Lee, S. Kamala-Kannan, *J. Hazard. Mater.* **241** (2012) 110
5. L. I. Cui, Q. Q. Meng, J. Y. Zheng, X. Wei, Z. F. Ye, *Vacuum* **89** (2013) 1
6. J. H. Shi, B. F. Lin, D. S. Xiao, J. W. Ding, *Appl. Chem. Ind.* **41** (2012) 609
7. T. Chen, T. Wang, D. J. Wang, J. Q. Zhao, X. C. Ding, S. D. Wu, H. R. Xue, J. P. He, *Acta. Phys. Chim. Sin.* **26** (2010) 3249
8. X. Xin, X. He, K. Cui, H. R. Chen, M. N. Sun, L. Yao, *J. Environ. Eng.* **4** (2010) 2273
9. C. H. Xu, D. D. Cheng, B. Y. Gao, Z. L. Yin, Q. Y. Yue, X. Zhao, *Front. Environ. Sci. Eng.* **6** (2012) 455
10. Y. Wu, J. Zhang, J. J. Xiao, J. M. Gao, Q. Zhao, *Wood Sci. Technol.* **48** (2014) 713
11. Y. Wen, Z. Tang, Y. Chen, Y. Gu, *Chem. Eng. J.* **175** (2011) 110
12. Y. Zhu, H. Zhang, H. Zeng, M. Liang, R. Lu, *Int. J. Environ. Sci. Technol.* **9** (2012) 463
13. N. Orakdogen, *Polym. Eng. Sci.* **53** (2013) 734
14. C. C. Li, L. Xu, M. L. Zhai, J. Peng, C. Yang, J. Q. Li, G. S. Wei, *Polymer* **50** (2009) 4888
15. C. C. Li, Y. W. Zhang, J. Peng, H. Wu, J. Q. Li, M. L. Zhai, *Radiat. Phys. Chem.* **81** (2012) 967
16. H. Tokuyama, N. Ishihara, *React. Funct. Polym.* **70** (2010) 610
17. H. M. Abdel-Aziz, T. Siyam, *Water Air Soil Poll.* **218** (2011) 165
18. W. X. Zhu, C. Yang, H. Song, Q. Y. Wang, K. F. Du, *Asian J. Chem.* **25** (2013) 2293
19. W. X. Zhu, H. Song, K. F. Du, H. Zeng, S. Yao, *J. Appl. Polym. Sci.* **128** (2013) 2729
20. X. D. Feng, *Makromol. Chem., Macromol. Symp.* **63** (1992) 1

21. J. Chen, M. Z. Liu, W. Chen, N. Y. Zhang, S. Y. Zhu, S. P. Zhang, Y Xiong, *J. Biomater. Sci. Polym. Ed.* **22** (2011)1568
22. C. C. Li, L. Xu, M. L. Zhai, J. Peng, J. Q. Li, *J. Appl. Polym. Sci.* **120** (2011) 2027
23. Q. Cheng, C. C. Li, L. Xu, J. Q. Li, M. L. Zhai, *Chem. Eng. J.* **173** (2011) 42
24. V. K. Gochev, Z. I. Velkova, M. S. Stoytcheva, *J. Serb. Chem. Soc.* **75** (2010) 551
25. Z. M. O. Rzaev, S. Dincer, E. Piskin, *Prog. Polym. Sci.* **32** (2007)534
26. H. L. Liu, M. Z. Liu, S. P. Jin, S. L. Chen, *Polym. Int.* **57** (2008)1165
27. Y. Chen, W. J. Xu, Y. Q. Xiong, C. Peng, W. Y. Liu, G. Z. Zeng, Y. Peng, *J. Mater. Res.* **28** (2013) 1394
28. G. Bayramoglu, M. Y. Arica, *Chem. Eng. J.* **139** (2008) 20
29. K. Tong, M. J. Kassim, A. Azraa, *Chem. Eng. J.* **170** (2011) 145
30. K. R. Hall, L. C. Eagleton, A. Acrivos, T. Vermeulen, *Ind. Eng. Chem. Fund.* **5** (1966) 212
31. G. Guclu, S. Keles, *J. Appl. Polym. Sci.* **106** (2007) 2422
32. M. Z. Momcilović, M. S. Randelović, A. E. Onjia, A. Zarubica, B. M. Babić, B. Z. Matović, *J. Serb. Chem. Soc.* **79** (2014) 481
33. Y. Liu, Y. Zheng, A. Wang, *J. Environ. Sci.* **22** (2010) 486
34. F. Haghseresht, G. Q. Lu, *Energ. Fuel* **12** (1998) 1100
35. K. Selvi, S. Pattabhi, K. Kadirvelu, *Bioresour. Technol.* **80** (2001) 87.