Adsorption/desorption performance of Pb$^{2+}$ and Cd$^{2+}$ with super adsorption capacity of PASP/CMS hydrogel

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ABSTRACT

Super-absorbent polyaspartic acid/carboxymethyl Salix psammophila powder (PASP/CMS) hydrogel was prepared by aqueous solution polymerization. PASP/CMS hydrogel was characterized by Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS). The results showed that PASP/CMS hydrogel is prepared by graft copolymerization of the -COOH of polyaspartic acid (PASP) and the -CH$_2$OH of CMS. The surface of the hydrogel became dense from loose porosity, and Pb$^{2+}$ and Cd$^{2+}$ were adsorbed onto the surface of hydrogel. The crystallinity of CMS was destroyed by the addition of PASP. The initial concentration of Pb$^{2+}$ and Cd$^{2+}$, pH, adsorption time and adsorption temperature on the adsorption effect were studied through experiments. Results showed that hydrogel has a good removal effect on Pb(II) and Cd(II) ions. Pseudo-second-order kinetics and Langmuir isotherm models are represented in the process, which are spontaneous, exothermic and decreased in randomness, and it is a single layer chemical adsorption. At the same time, the effect of desorption experimental parameters (HNO$_3$ initial concentration, desorption time, and desorption temperature) on the experiment was studied and optimized.

Key words: adsorption, cadmium ion (II), carboxymethyl salix (CMS), desorption, hydrogel, lead ion(II)

HIGHLIGHTS

- With the addition of PASP, the structure of CMC was destroyed and PASP/CMS hydrogel was formed.
- The adsorption of lead and chromium ions by hydrogels accords with the Langmuir isothermal model and quasi-second-order kinetic model.
- The adsorption is a monolayer chemical adsorption.
- The adsorption is a spontaneous exothermic process.
- The heavy metal ions were adsorbed on the surface of the hydrogel.

INTRODUCTION

The relative density of heavy metals is high, especially for lead, mercury, cadmium, chromium (Ma et al. 2018). Sources mainly include the arbitrary discharge of industrial wastewater and waste residue. Heavy metals influence water, soil and human beings (Naushad & AlOthman 2015; Du et al. 2016). Among the various technologies for treating metal ions, adsorption is the most effective method, and the adsorbent is very important (Naushad 2014; Marinah et al. 2017; Ma et al. 2018; Sofiah et al. 2018). The traditional adsorbent has the disadvantages of non-regeneration, causing secondary pollution to the environment (Xiong et al. 2016). Therefore, environmentally friendly adsorbents have attracted increasing attention in recent years.

Salix psammophila (SPP) is a renewable resource in nature, and can grow in saline-alkali land, it has the characteristics of strong regeneration and wide source, and has been investigated by many researchers (Liu et al. 2018; Hao & Li 2019). Cellulose and lignin are present in SPP, and the hydroxyl group is the main active ingredient. By breaking the binding effect of hydrogen bonds in SPP, the adsorption performance of hydroxyl groups can be better developed and its application field can be expanded. Carboxymethyl salix wood powder was prepared by treating alkalized salix powder with monochloroacetic acid, and its adsorption performance in methylene blue solution was studied in our past research (Li et al. 2016). It was indicated that adsorption capacity of methylene blue...
solution (1,908 mg/g) onto carboxymethyl salix wood powder was higher than for salix (257 mg/g). It is an excellent polymer adsorbent in nature.

Polyaspartic acid (PASP), as a polyamino acid, which not only has the performance of water-soluble carboxylic acid (Yang et al. 2019), but also the strong functions of chelation, adsorption and dispersion due to its side-chain hydroxyl group. In addition, PASP has been explored because of its valuable biodegradability (Jv et al. 2019), but its single functional group and poor adsorption performance limit its application. Polyaspartic acid/lignocellulose (PASP/LNC) hydrogel was prepared and the adsorption performance of Pb²⁺ onto PASP/LNC hydrogel was studied in our past research (Ye & Wang 2016). It was shown that PASP/LNC hydrogel has good adsorption performance for Pb²⁺, and its adsorption capacity for Pb²⁺ was as high as 972.35 mg/g.

Hydrogel is a kind of high polymer which is hydrophilic but insoluble in water and can rapidly reach the swelling equilibrium. There are many functional groups (–OH, –COOH and –NH₂, etc.). These functional groups can adsorb and exchange ions with heavy metal ions (Xiong et al. 2016). Hydrogel, as an absorbent, has become a popular option to treat heavy metal ions due to its high adsorption capacity, high adsorption speed and recyclability (Song et al. 2020). Wang et al. prepared (Wang & Wang 2016) polyvinyl alcohol/carboxymethyl cellulose (PVA/CMC) hydrogel using the freeze–thaw method and studied its performance. The research results confirmed that the adsorption capacity of the PVA/CMC hydrogel for Ag⁺ was higher (8.2 mg/g) than that of PVA hydrogel for Ag⁺ (4.7 mg/g). Therefore, PVA/CMC hydrogel prepared in this study can be used to treat heavy metal ions.

To date, adsorption/desorption performance of heavy metal ions by polyaspartic acid/carboxymethyl salix wood powder (PASP/CMS) hydrogel has been rarely reported at home and abroad. Here, PASP/CMS hydrogels were prepared and adsorption/desorption performance of Pb²⁺ and Cd²⁺ were studied. The adsorption isotherm, kinetic and thermodynamic models of Pb²⁺ and Cd²⁺ onto hydrogel were explored.

MATERIALS AND METHODS

Materials

SPP is produced in Erdos Xinjie, Inner Mongolia. KMnO₄, glutaraldehyde, ethylenediamine tetraacetic acid disodium, and nitric acid were produced by Sinopharm Chemical Reagent Co., Ltd. PASP, lead nitrate, cadmium nitrate, hexamethylenetramine and xylenol orange were produced by Shandong West Asia Chemical Industry Co., Ltd, concerned with development of fine chemicals for wind boats in Tianjin Co., Ltd, Hunan Jinjinle Chemical Co., Ltd, Hongyan Reagent Factory, Hedong District, Tianjin, and Tianjin Shengao Chemical Reagent Co., Ltd, respectively.

Preparation of CMS

SPP was pulverized, sieved through a 200-mesh and dried; 2 g of the dried SPP was immersed in 15% sodium hydroxide solution for 12 h, filtered, and transferred into a flask, and 20 mL of absolute ethanol was added. Chloroacetic acid was added in batches, reacted at room temperature for 30 minutes, then reacted at 60 °C for 2 hours, then filtered and dried to obtain CMS.

Preparation of PASP/CMS hydrogel

The CMS (0.1 g) and KMnO₄ solutions (0.06 mol/L, 50 mL) were added into a three-necked flask, and mechanically stirred in a water bath for 15 min at 50 °C. Next, 20 mL of distilled water, CMS pretreated with KMnO₄, 15 g of PASP, and 1.0 g of glutaraldehyde were put into the three-necked flask, and reacted at 70 °C for 3.5 h. The product was dried in an oven at 105 °C.

Characterization

FTIR was used to test CMS and PASP/CMS hydrogel with an FTIR spectrometer (6701F, Japan JSM Company). The samples were treated with KBr, and the FTIR spectra were recorded at a resolution of 4 cm⁻¹ and the scanning ranges 500–4,000 cm⁻¹, and 160 scans per sample.

XRD was used to test CMS and PASP/CMS hydrogel with an X-ray diffractometer (Tensor27, Germany Bruker Company). The samples were placed on a blank slide with an incident wavelength of 0.514 nm, scanning ranges 5–60°, and speed of 4°/min, and interval of 0.02°, CuKα target wavelength.

SEM was used to test samples on a scanning electron microscope (XRD-6000, Japan Shimadzu Company), and were observed under the conditions of accelerating voltage of 5 kV and magnification of 40,000 times.
XPS was used to test samples on an X-ray electron spectrophotometer (ESCALAB21, British VG Company). AlKα target wavelength was used as excitation source, photoelectron energy was 1486.6 eV, electron binding energy was corrected with 284.6 eV of Cls as reference, and eigenvalue error was ±0.47 eV.

**Adsorption of Pb²⁺ and Cd²⁺ by PASP/CMS hydrogel**

A solution containing metal ions was prepared at specified concentrations, 5 mL was transferred into a conical flask, the pH was adjusted with buffer solution. Ion concentration in solution was determined by EDTA complexometric titration. Next, 50 mL of the prepared solution was transferred to another conical flask, the pH was adjusted to the set value, 0.1 g of adsorbent was added into the conical flask and shaken on an oscillator. Then, 5 mL of supernatant was added to the conical flask after adsorption equilibrium, and pH adjustment, 2–3 drops of xylanol orange solution were added into the solution to color Pb²⁺ and Cd²⁺. Molar concentration of the residual ions in solution is determined by complexometric titration. The equation of adsorption capacity \( Q_e \) (mg/g) is shown in (1) (Yatim et al. 2018):

\[
Q_e = \frac{(C_0 - C_e) \times V \times M}{m}
\]

where,

- \( C_0 \) (mol/L): initial molar concentration;
- \( C_e \) (mol/L): the molar concentration of the adsorption equilibrium;
- \( V \) (mL): volume;
- \( M \) (g/mol): relative atomic mass (Pb: 207.2 g/mol; Cd: 112.4 g/mol);
- \( m \) (g): the mass of hydrogel.

**Desorption of Pb²⁺ and Cd²⁺ by PASP/CMS hydrogel**

Then, 50 mL of HNO₃ solution, and 0.1 g of adsorbent saturated with adsorption were added to a conical flask, and then put into a constant temperature water bath oscillator. The PASP/CMS hydrogel was desorbed (determined temperature and time), and was centrifuged for 5 min after desorption reached equilibrium. The method for determining the molar concentration of ions is the same as above. The desorption capacity \( Q_t \) (mg/g) is shown in Equation (2):

\[
Q_t = \frac{C_t \times V \times M}{m}
\]

where, \( C_t \) (mol/L): the molar concentration after desorption.

**RESULTS AND DISCUSSION**

**FTIR**

Figure 1(a) shows the FTIR spectra of CMS and PASP/CMS hydrogel. The characteristic peaks at 3,442, 2,900, 1,598 and 1,423 cm⁻¹ were assigned to -OH, -CH, -COOH and -CH₂OH stretching vibrations of CMS. The absorption peak of the PASP/CMS hydrogel was enhanced at 3,444 cm⁻¹ after graft copolymerization of CMS and PASP, which was attributed to the introduction of PASP containing hydroxyl side chains. Therefore, the number of hydroxyl groups increases after graft polymerization. The peak enhancement at 2,904 cm⁻¹ was attributed to the introduction of long saturated alkane chains into the PASP/CMS hydrogel after polymerization (Gaurav et al. 2017). The peak enhancement at 1,602 and 1,407 cm⁻¹ indicated that the hydrogel was formed by graft copolymerization of the -COOH of PASP and the -CH₂OH of CMS.

**XRD**

Figure 1(b) shows that the XRD spectra of CMS and PASP/CMS hydrogel. The characteristic diffraction peak of CMS was at \( 2\theta = 21.91^\circ \), and the characteristic peak of PASP/CMS hydrogel was obviously weakened here, indicating that the order of CMS was destroyed and crystallinity was decreased with the addition of PASP, which added the side-chain hydroxyl group in PASP. The diffraction peak at \( 2\theta = 31.22^\circ \) was observed, which was the crystalline structure of cellulose I and the characteristic diffraction peak of CMS, indicating that CMS has been grafted onto PASP and formed the PASP/CMS hydrogel, which was consistent with the infrared analysis results.
SEM

SEM of PASP/CMS hydrogel (a) and PASP/CMS hydrogel adsorption Pb\(^{2+}\) (b) and Cd\(^{2+}\) (c) are shown in Figure 2. The images clearly indicated the loose and porous surface of PASP/CMS. The surface of the hydrogel became dense after the reaction, indicating that ions were successfully adsorbed on that the surface of the hydrogel.

XPS

The XPS spectra of the PASP/CMS hydrogel (a) and PASP/CMS hydrogel adsorption of Pb\(^{2+}\) (b), Cd\(^{2+}\) (c) are shown in Figure 3. Peaks for Pb4f (139 eV) and Cd3d (412 eV) were detected in the adsorbed hydrogel with Pb\(^{2+}\) and Cd\(^{2+}\), indicating that the active sites on the surface of the hydrogel had been filled with heavy metal ions, which was consistent with the SEM analysis results.

Adsorption of Pb\(^{2+}\) and Cd\(^{2+}\) by PASP/CMS hydrogel

Initial concentrations of Pb\(^{2+}\) and Cd\(^{2+}\)

Figure 4(a) shows the effect of initial ions concentration on adsorption of Pb\(^{2+}\) and Cd\(^{2+}\) by the PASP/CMS hydrogel. The extent of Pb\(^{2+}\), Cd\(^{2+}\) removal by PASP/CMS hydrogel increased first and then decreased with the increase in initial concentration. The absorption capacity reached the maximum value at 0.04 mol/L, and the maximum value was 1,657.6 and 719.6 mg/g on the PASP/CMS hydrogel for Pb\(^{2+}\) and Cd\(^{2+}\), respectively. This can be attributed to the presence of more Pb\(^{2+}\) and Cd\(^{2+}\), which can provide a higher driving force for effective collision between ions and active sites of the hydrogel, thereby promoting the transfer of ions between the two phases (diffusion from the solution phase to PASP/CMS hydrogel phase) and more collisions between ions and active sites of the hydrogel. The hydrolysis of the metal ions in solution was promoted with the increase in ion concentration, the adsorption capacity of hydrogel for adsorbing the ions was reduced (Wang et al. 2019). Therefore, the initial concentration of 0.04 mol/L was reasonable.

pH of solution

Figure 4(b) shows that the adsorption capacity first increased to the maximum and then decreased with the increase in pH. The absorption capacity reached the maximum value at pH 5.5, and maximum value was 1,656.4 and 717.3 mg/g on the PASP/CMS hydrogel for Pb\(^{2+}\) and Cd\(^{2+}\), respectively. At lower pH, the high concentration of H\(^+\) present competed with Pb\(^{2+}\) and Cd\(^{2+}\) at active sites. In addition, the amino, carboxyl and other groups in the hydrogel were protonated to have positive charges, which generated electrostatic repulsion with the Pb\(^{2+}\) and Cd\(^{2+}\) in solution. The adsorption capacity was reduced because the diffusion of heavy metal ions was reduced (Gamze et al. 2010). When the pH was greater than 5.5, the concentration of -OH in the solution increased, resulting in the hydrolysis of metal ions and destruction of the hydrogel network structure, and the adsorption capacity was reduced (Gaurav et al. 2017). Therefore, it is reasonable to choose the pH of the solution to be 5.5.

Adsorption time

Figure 4(c) shows that the adsorption capacity was first increased to a maximum and then gradually leveled off with time. The absorption capacity reached the maximum value at 60 min, and maximum value was 1,657.2 and 718.4 mg/g on the PASP/
CMS hydrogel for 

\[ \text{Pb}^{2+} \] and \[ \text{Cd}^{2+} \], respectively. Heavy metal ions were more easily contacted abundant active sites on the hydrogel surface at the early stage of the adsorption reaction, and adsorption capacity was continuously increased with time. In the late adsorption period, the adsorption sites of hydrogels were gradually saturated, and the adsorption capacity gradually reached equilibrium until reaching adsorption saturation with time. Therefore, it is reasonable to choose the adsorption time to be 60 min.

**Adsorption temperature**

Figure 4(d) shows that the adsorption capacity decreased with the increase in adsorption temperature. At a temperature of 30 °C (which is close to room temperature and easy to control), the absorption capacity reached the maximum value, and
was 1,657.5 and 719.2 mg/g on the PASP/CMS hydrogel for Pb$^{2+}$ and Cd$^{2+}$, respectively. The heavy metal ions were easily desorbed into the solution by removing the interactions within the hydrogel with the temperature increase, thereby causing the adsorption capacity to reduce. The adsorption reaction was an exothermic reaction, which was consistent with the adsorption thermodynamics, and was not conducive to the adsorption of the hydrogel by increasing temperature. Therefore, it is reasonable to choose the adsorption temperature to be 30 °C.

**Adsorption isotherm model**

Langmuir and Freundlich models were used to analyze the experimental data (Maneechakr & Karnjanakom 2017). The models are given in Equations (3) and (4).

**Langmuir:**

\[
\frac{c_e}{q_e} = \frac{1}{b q_m} + \frac{c_e}{q_m}
\]

**Freundlich:**

\[
q_e = k_f c_e^{1/n}
\]

where,

$q_e$ (mg/g): equilibrium adsorption capacity;
$q_m$ (mg/g): theoretical adsorption capacity;
$k_f$: constant;
$n$: constant.

Figure 5(a) and 5(b) show the adsorption isotherm models. Table 1 shows that parameters of the adsorption isotherm. In Table 1, $R^2$ values of Langmuir models for adsorption of Pb$^{2+}$ and Cd$^{2+}$ onto PASP/CMS hydrogels were 0.9957 and 0.9913, respectively, and the theoretical adsorption capacity (1,954.7 and 847.5 mg/g) was not much different from the actual adsorption capacity (1,657.6 and 719.6 mg/g). In addition, $R^2$ values of Freundlich models for adsorption of Pb$^{2+}$ and Cd$^{2+}$ onto hydrogels were 0.9045 and 0.9278, respectively. To sum up, the adsorption reaction accords with the Langmuir isothermal model, which is monolayer chemisorption.

![Figure 5](image-url)

**Figure 5** | Langmuir models for the adsorption of Pb$^{2+}$ (a), Cd$^{2+}$ (b) and Freundlich models for the adsorption of Pb$^{2+}$ (c), Cd$^{2+}$ (d) onto PASP/CMS hydrogels.

**Table 1** | The parameters of the Langmuir and Freundlich models for adsorption of Pb$^{2+}$, Cd$^{2+}$ onto PASP/CMS hydrogels

|   | Langmuir | Freundlich |
|---|----------|------------|
|   | $q_m$    | $b$        | $R^2$   | $k_f$    | $1/n$     | $R^2$   |
| Pb$^{2+}$ | 1,954.7  | 0.0002     | 0.9957  | 1.6858   | 0.7342    | 0.9045  |
| Cd$^{2+}$ | 847.5    | 0.0001     | 0.9913  | 16.4220  | 0.4089    | 0.9278  |
Adsorption kinetic model

Adsorption equilibrium and mechanism can be better explained by using pseudo-first-order and pseudo-second-order kinetic models (Saruchi & Vaneet 2019). Here, the kinetic models are shown in Equations (5) and (6), respectively.

Pseudo-first-order kinetic rate equation:

\[
\log\left(\frac{q_e - q_t}{q_t}\right) = \log\left(\frac{q_e}{C_0}\right) - \frac{K_1 t}{2.303}
\]  

Equation (5)

Pseudo-second-order kinetic rate equation:

\[
\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e}
\]

Equation (6)

where,

\[q_t\ (\text{mg/g})\]: adsorption capacity at time t;
\[K_1\ (\text{min}^{-1})\]: the rate constant of pseudo-first-order kinetic;
\[K_2\ (\text{mg/g min}^{-1})\]: the rate constant of pseudo-second-order kinetic.

Figure 6 and Table 2 show the pseudo-first-order, pseudo-second-order kinetic models and parameters. In Table 2, \(R^2\) values of the pseudo-first-order and the pseudo-second-order kinetic models for adsorption of \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\) onto PASP/CMS hydrogels were 0.9720 (0.9552) and 0.9932 (0.9944), respectively, and the theoretical adsorption capacities were 1,480.3 (1,388.9) and 1,785.7 (808.4) mg/g, respectively. The maximum adsorption capacity of \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\) adsorbed on the hydrogel in the test was 1,657.6 (719.6) mg/g. From the analysis data, the adsorption reaction was more in line with the pseudo-second-order kinetic model, and chemical adsorption was dominant in the process, which was consistent with the analysis result of the adsorption isotherm model.

Adsorption thermodynamics

The adsorption degree and internal driving force of adsorbent to adsorbate can be studied by adsorption thermodynamics (Saruchi et al. 2019), Gibbs and van’t Hoff equations (Seyed et al. 2020) are shown in Equations (7) and (8):

\[
\Delta G = \Delta H - T\Delta S
\]

Equation (7)

\[
\ln \left(\frac{q_e}{C_e}\right) = \frac{-\Delta H}{R T} + \frac{\Delta S}{R}
\]

Equation (8)

where,

\[\Delta G\ (\text{kJ/mol})\]: Gibbs free energy;
\[\Delta H\ (\text{kJ/mol})\]: adsorption enthalpy;
\[\Delta S\ (\text{kJ/(mol·K)})\]: adsorption entropy;
\[T\ (\text{k})\]: adsorption temperature;
\[R\ (8.314 \times 10^{-3}\text{kJ/(mol·K)})\]: the ideal gas constant.

Figure 6(e) and 6(f) show the van’t Hoff equations. Tables 3 and 4 show the thermodynamic parameters of adsorption of \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\) onto PASP/CMS hydrogels. The values for analytical parameters available, adsorption enthalpy \(\Delta H\), Gibbs free energy \(\Delta G\), and adsorption entropy \(\Delta S\) were all negative, indicating that the adsorption process was an exothermic reaction (Mensah et al. 2019). The decrease in adsorption capacity was mainly caused by the increase in adsorption temperature (see Adsorption temperature). The adsorption processes are spontaneous and decreased randomness.

Desorption of \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\) onto PASP/CMS hydrogel

HNO_3 concentration

Figure 7(a) shows the effect of HNO_3 concentration on desorption capacity of PASP/CMS for \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\). The desorption capacity was found to be first increased to a maximum and then decreased with the increase in the HNO_3 concentrations.
The desorption capacities were 580.2 and 382.2 mg/g when HNO₃ concentration was 0.08 mol/L. The affinities of the hydrogel to different ions were different, and for the size of the affinities: the hydrogen ion is greater than lead ion(II) and cadmium ion(II). Therefore, the desorption capacity of Pb²⁺ and Cd²⁺ onto PASP/CMS hydrogel increased with the increase in HNO₃ concentration. The concentration of H⁺ in solution increased, and the H⁺ and Pb²⁺, Cd²⁺ produced electrostatic repulsion, which inhibited the desorption of Pb²⁺ and Cd²⁺ and reduced the desorption capacity (Mensah et al. 2019). Therefore, it is reasonable to choose the 0.08 mol/L HNO₃ concentration.

**Figure 6** | Pseudo-first-order kinetic models for the adsorption of Pb²⁺ (a) and Cd²⁺ (b), pseudo-second-order kinetic models for the adsorption of Pb²⁺ (c) and Cd²⁺ (d), and van 't Hoff equations for the adsorption of Pb²⁺ (e) and Cd²⁺ (f) onto PASP/CMS hydrogels.
Desorption time

Figure 7(b) shows that the effect of desorption time. The results showed that desorption of Pb^{2+} and Cd^{2+} by PASP/CMS increased first and then stabilized with time. The maximum desorption capacities of the PASP/CMS hydrogel for Pb^{2+} and Cd^{2+} were 579.6 and 381.6 mg/g, respectively. At the early stage, the existence of a large amount of H^{+} in the solution formed competitive adsorption with the saturated hydrogel, thus the desorption capacity of the hydrogel was increased. At the later stage, the concentration difference between Pb^{2+}, Cd^{2+} on PASP/CMS hydrogel and H^{+} in solution became smaller, the desorption capacity gradually became stable and the final desorption capacity was unchanged. Therefore, it is reasonable to choose the desorption time to be 90 min.

Desorption temperature

Figure 7(c) shows that desorption capacity was first increased and then gradually leveled off with the increase in desorption temperature. The maximum desorption capacities of the PASP/CMS hydrogel for Pb^{2+} and Cd^{2+} at 60 °C, and maximum desorption were 580.1 and 381.6 mg/g, respectively. At the early stage, the existence of a large amount of H^{+} in the solution formed competitive adsorption with the saturated hydrogel, thus the desorption capacity of the hydrogel was increased. At the later stage, the concentration difference between Pb^{2+}, Cd^{2+} on PASP/CMS hydrogel and H^{+} in solution became smaller, the desorption capacity gradually became stable and the final desorption capacity was unchanged. Therefore, it is reasonable to choose the desorption temperature to be 60 °C.

CONCLUSIONS

A new hydrogel, PASP/CMS was synthesized by graft copolymerization and characterized by Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS). It was found to be an excellent adsorbent for the removal of Pb^{2+} and Cd^{2+} from aqueous medium.
The adsorption of Pb\(^{2+}\) and Cd\(^{2+}\) onto the PASP/CMS hydrogel reached maximum at the initial concentration 0.04 mL/L, pH 5.5, shaking time 60 min, and temperature 30 °C, which were 1,657.6 and 719.6 mg/g, respectively. The desorption of Pb\(^{2+}\) and Cd\(^{2+}\) onto the PASP/CMS hydrogel reached maximum at the HNO\(_3\) concentration 0.08 mL/L, pH 5.5, desorption time 90 min, and temperature 60 °C, which were 580.16 and 382.16 mg/g, respectively. The results show that the adsorption process accords with the Langmuir isotherm and quasi-second-order kinetic models, and is a spontaneous exothermic reaction with the degree of chaos decreasing in the process.

The PASP/CMS hydrogel has ultra-high adsorption capacity for heavy metal ions (such as Pb\(^{2+}\), Cd\(^{2+}\)), and has excellent performance including environmental protection, economy and regeneration, which provides the certain theoretical basis for treatment of metal ions (such as Pb\(^{2+}\), Cd\(^{2+}\)) in wastewater.

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DATA AVAILABILITY STATEMENT
All relevant data are included in the paper or its Supplementary Information.

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