

Adsorption and Desorption Properties of Modified Feather and Feather/PP Melt-Blown Filter Cartridge of Lead Ion (Pb^{2+})

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ABSTRACT: Duck and chicken feather fibers are waste products of the poultry industry, creating a serious solid waste problem around the world. Previous works showed that feather fibers can be reused to adsorb heavy metal ions from water. To improve the adsorption capacity of feather fibers, sodium pyrosulfite ($\text{Na}_2\text{S}_2\text{O}_5$) was used in this article to modify the feather fiber in order to improve its Pb^{2+} adsorption capacity. Scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) quantified chemical and structural changes of $\text{Na}_2\text{S}_2\text{O}_5$ modified feather fibers. In addition, $\text{Na}_2\text{S}_2\text{O}_5$ modified feather fibers were processed into feather/polypropylene (PP) melt-blown filter cartridges and their dynamic Pb^{2+} adsorption properties were investigated. Finally, the desorption effects of NaOH and sodium sulfide nonahydrate ($\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$) aqueous solutions on the feather fiber adsorbed with Pb^{2+} were studied. It is found that Pb^{2+} adsorption capacity of the feather fiber increased after being modified by $\text{Na}_2\text{S}_2\text{O}_5$. Modified feather/PP filter cartridge exhibited higher Pb^{2+} adsorption capacity than feather/PP filter cartridge and pure PP filter cartridge in the whole dynamic adsorption process. © 2014 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2015**, *132*, 41555.

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INTRODUCTION

The wastewater generated from many industries, such as tanning, battery, glassware, ceramics, electroplating, mining, paints, and photographic industry, contains a number of heavy metal ions like chromium, lead, cadmium, etc., which have significant toxic effects and these pollutants requires removal before discharge into the main stream.¹ Long term drinking water containing Pb^{2+} ion, even at very low concentrations, could lead to a broad spectrum of health problems, including nausea, convulsions, coma, renal failure, cancer and subtle effects on metabolism and intelligence.²

Different approaches to remove Pb^{2+} ions from wastewaters, including chemical precipitation, ion exchange, reverse osmosis and adsorption, have been reported. Among them, adsorption is one of the most important methods because of its easy operation and versatility.³ Various adsorbents have been explored to remove heavy metal ions from wastewaters. Biosorption material, a kind of low-cost adsorbent with excellent sorption capacity, is gaining more and more attention. However, the relatively low metal uptake, the high brittleness of the biomass, and the inherent poor reproducibility have limit the feasibility of biosorption. Compared to other biomass sorbents, the feather

fiber comprises of excellent mechanical properties, resists hydrolytic degradation, and is durable.

It is said that the feather fiber is constituted with four parts from outside to inward, which are named as epicuticle film, cuticle layer, skin layer and cortex, of which the epicuticle film is a layer of biologic cell membrane. The cell membrane is mainly made of sterol and bimolecular layers of triphosphate ester, these chemicals are responsible for the excellent water repellent properties of feather fibers.⁴ But as a biomass sorbent, the hydrophobic properties of the feather fiber is a serious drawback in the processing of aqueous metal ion solutions. The raw feather fiber only exhibits moderate heavy metal ions adsorption capacity, not cost-effective to be reused as adsorbent in a large scale.

Recently, much research has focused on the sorption properties of feather fibers as sorbents for the removal of heavy metals, phenol and organic dyes from their aqueous solutions.^{5–9} Banat et al. compared the sorption capacities of some keratin-based compounds, including the feather fiber, for the removal of Zn^{2+} ions from aqueous solutions in a batch configuration and using different conditions of pH and temperature.¹⁰ The research on Zn^{2+} adsorption properties of feather fiber before

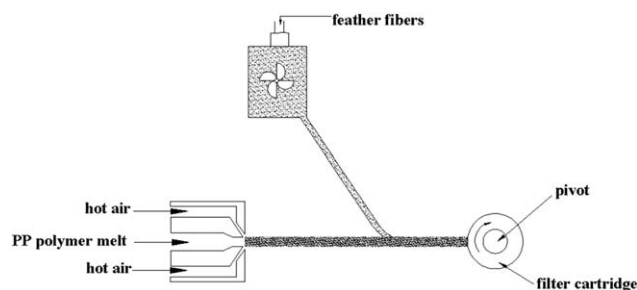


Figure 1. Schematic diagram of the production process of feather/PP melt-blown filter cartridge.

and after chemical treatment showed that the feather fiber treated with alkaline aqueous solutions adsorbed more metal ions than those treated with an anionic surfactant and untreated feather fiber.¹¹ Many research works have been carried by chemical grafting, alkaline treatment, powdering, dissolution, etc., to improve the adsorption capacity of the feather fiber.¹² Reduction is the main method of dissolving wool, where the disulfide bonds of keratin are cleaved.¹³ Sodium pyrosulfite ($\text{Na}_2\text{S}_2\text{O}_5$) aqueous solution, one of the important reducing reagents, is widely used to dissolve wool or remove the scale of wool. Wang and Liu¹⁴ inferred that it can be used to modify the feather fiber for improving its Pb^{2+} adsorption capacity.

In another study, Kar and Misra reported the removal of Zn^{2+} using the feather fiber in a multicomponent aqueous solution of Cu^{2+} , Pb^{2+} , Zn^{2+} , Cd^{2+} , and Ni^{2+} at different pH values.¹⁵ Most of the above mentioned studies on the removal of Zn^{2+} ions using the feather fiber have been focused on sorption experiments using batch configurations. Aguayo-Villarreal et al. first studied the removal of zinc ions from aqueous solution by raw chicken feathers using both batch and continuous systems.¹⁶ Duck feather was processed into a kind of composite made from nonwoven fabric with bicomponent fiber, which showed good mechanical properties and adsorption capacities of Cu^{2+} and Cr(VI) aqueous solution.¹² As we know, melt-blown filter cartridge is widely used nowadays to clean water, filtering out insoluble impurities. It is significant to endow it with heavy metal ions adsorption property at the same time. In this article, feather/polypropylene melt-blown filter cartridges were prepared and their dynamic Pb^{2+} adsorption properties were investigated as well.

In addition, recovering the metal biosorbed or reusing the biomass is one of the essential issues to scale up bio-sorption technology. This work will examine the effects of NaOH and sodium sulfidenonahydrate ($\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$) as eluents to regenerate the feather fiber adsorbed with Pb^{2+} .

MATERIALS AND METHODS

Materials

The duck feather fiber without scapus was supplied by Yangzhou Ganquan Down Products Factory. Polypropylene (PP) with melt flow index (MFI) 35 g min^{-1} was purchased from Sinopec Shanghai Petrochemical Company. Lead nitrate ($\text{Pb}(\text{NO}_3)_2$) was used to prepare Pb^{2+} solution. Sodium hydroxide (NaOH) and sodium sulfide nonahydrate ($\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$) were used as desorp-

tion reagents. Sodium pyrosulfite ($\text{Na}_2\text{S}_2\text{O}_5$) and urea were used to modify feather fibers. Nitric acid (HNO_3) was used in the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) measurement. Ammonia aqueous solution ($\text{NH}_3\cdot\text{H}_2\text{O}$) was used to adjust the pH value of solutions.

$\text{Na}_2\text{S}_2\text{O}_5$ Modification of the Feather Fiber

Nearly 1–15 g $\text{Na}_2\text{S}_2\text{O}_5$ were added into 200 mL deionized water to obtain aqueous solutions with concentrations of 0.026–0.395 M, respectively. About 20 g urea was added to every solution and was heated to 65°C . A 10 g feather fiber (1.57 cm long with diameter of $26 \mu\text{m}$) was put into the above solutions, respectively. The solutions were stirred for 5 min and then were allowed to stand for 2 h. Finally, the solutions were filtered and feather fibers were washed thoroughly with deionized water and air-dried at room temperature for further use.

Preparation of Feather/Polypropylene (PP) Melt-Blown Filter Cartridges

Feather/PP melt-blown filter cartridges were made by fixing an extra feather fiber feeding unit on a traditional melt-blown nonwoven production machine, as shown in Figure 1. The feather fiber was blown out by a fan uniformly from the unit and mixed with PP melt-blown nonwoven fibers spun from the spinneret of the melt-blown equipment and reached a pivot with a core, which rotated and moved back and forth to form the cylindrical shape of a filter cartridge. In this article, three kinds of filter cartridges were made, i.e., feather/PP melt-blown filter cartridge, modified feather/PP melt-blown filter cartridge and pure PP melt-blown filter cartridge. Their structural properties are listed in Table I. The feather/PP melt-blown filter cartridge is shown in Figure 2. Feather/PP and modified feather/PP melt-blown filter cartridges are constituted with multilayers. The inner layer is composed of pure PP melt-blown nonwoven fibers, the middle layer is composed with the feather fiber and PP melt-blown nonwoven fiber in a ratio listed in Table I, and the outer layer is composed of pure PP melt-blown nonwoven fibers to endow the whole filter cartridge with high physical and mechanical properties. The inside diameter of the cartridge is 30 mm and the length of the cartridge is 250 mm.

Adsorption Experiment of the Feather Fiber with and Without $\text{Na}_2\text{S}_2\text{O}_5$ Modification

About 2 g Duck feather fiber with and without $\text{Na}_2\text{S}_2\text{O}_5$ modification was immersed in 250 mL $\text{Pb}(\text{NO}_3)_2$ aqueous solution

Table I. Properties of Feather/PP Melt-Blown Filter Cartridges

Samples	Feather/PP	Modified feather/PP	PP
Weight of filter cartridge (g)	164	163	158
Content of feather fibers (%) ^a	48.8	49.1	0
Outer diameter (mm)	64	64	66

^a Content of feather fibers is the ratio of the weight of feather fibers to the weight of the filter cartridge expressed as a fraction of 100.

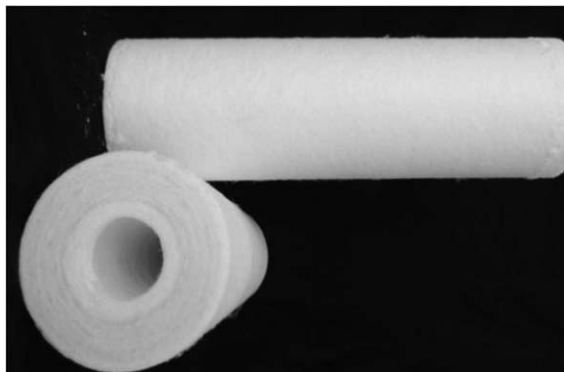


Figure 2. Feather/PP melt-blown filter cartridge.

containing $100 \text{ mg L}^{-1} \text{ Pb}^{2+}$ at 25°C . The solution was stirred for 5 min and then was allowed to stand for 1 h. Finally, the solution was filtered and the residual Pb^{2+} concentration of the filtrate was measured by using ICP-AES. The Pb^{2+} adsorption capacity of the feather fiber is calculated according to eq. (1).

$$Q_1 = \frac{(C_0 - C_1) \times V_1}{M_1} \quad (1)$$

where Q_1 is Pb^{2+} adsorption capacity of the feather fiber (mg g^{-1}) with and without $\text{Na}_2\text{S}_2\text{O}_5$ modification, C_0 is the initial Pb^{2+} concentration of $\text{Pb}(\text{NO}_3)_2$ aqueous solution (M); C_1 is the residual Pb^{2+} concentration in $\text{Pb}(\text{NO}_3)_2$ aqueous solution after adsorption (M); V_1 is the volume of $\text{Pb}(\text{NO}_3)_2$ aqueous solution (L); and M_1 is the weight of the feather fiber before adsorption (g).

Dynamic Pb^{2+} Adsorption Measurement of Filter Cartridges

Most studies on the removal of heavy metal ions using the feather fiber have been focused on sorption experiments using batch configurations. In this article, melt-blown filter cartridge was prepared and dynamic Pb^{2+} adsorption test equipment was set up by ourselves. The melt-blown filter cartridge was fixed by hot-melt adhesive on both ends with two end caps, one of which has hole in the center as shown in Figure 3(b). The end of the cartridge with hole was inserted into the support post of the filter cartridge vessel, as shown in Figure 3(c).

Dynamic Pb^{2+} adsorption equipment was set up in our lab as shown in Figure 4, which is constituted with pressure gauge, flow meter, filter cartridge and pump. $\text{Pb}(\text{NO}_3)_2$ aqueous solution with concentration of about 0.3 mM was sucked from the reservoir by the pump. It flowed through the valve, pressure gauge 1 and flow meter 1, and then went into the filter cartridge from the outer layer into the inner layer and then flowed out from the hole under the filter cartridge. The solution went through pressure gauge 2 and flow meter 2 and went back to the reservoir, and then repeated in this way. A small amount of the solution was taken from the reservoir every 30 min and Pb^{2+} concentration was measured by using ICP-AES.

Desorption Experiment

Nearly 2 g duck feather fibers adsorbed Pb^{2+} from the above Pb^{2+} adsorption experiment were washed thoroughly with deionized water and air-dried at room temperature. Then they were immersed in 250 mL NaOH and $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ aqueous solutions with a series of concentrations (0.01 – 0.05 M) at 40°C for 1 h, respectively. Finally, the solutions were filtered and Pb^{2+} concentration of the residual solutions were measured by using ICP-AES. The desorption capacity of the feather fiber under different solutions is calculated according to eq. (2).

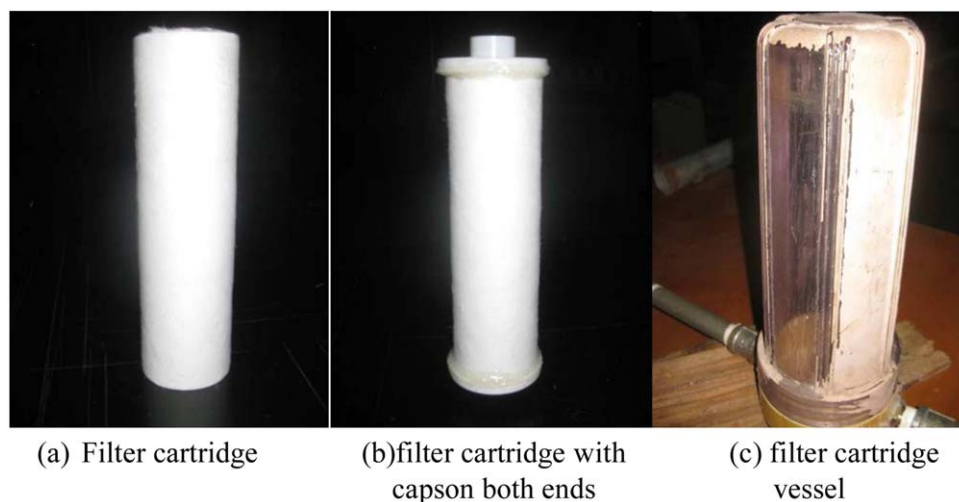
$$Q_2 = \frac{C_2 \times V_2}{M_2} \quad (2)$$

where Q_2 is the desorption capacity of the feather fiber (mg g^{-1}); C_2 is Pb^{2+} concentration of the desorption solution (M); V_2 is the volume of the desorption solution (L); and M_2 is the weight of the feather fiber used in the experiment (g).

Duck feather fiber after NaOH desorption experiment was used to adsorb Pb^{2+} according to the above procedure of adsorption experiment. Its Pb^{2+} adsorption capacity was measured by the same method. The adsorption and desorption experiment was repeated 12 times.

Measurements

Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). ICP-AES was used to measure Pb^{2+} concentration in the solution. The detection limits for most elements are



(a) Filter cartridge

(b) filter cartridge with capson both ends

(c) filter cartridge vessel

Figure 3. Installation system of the melt-blown filter cartridge. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

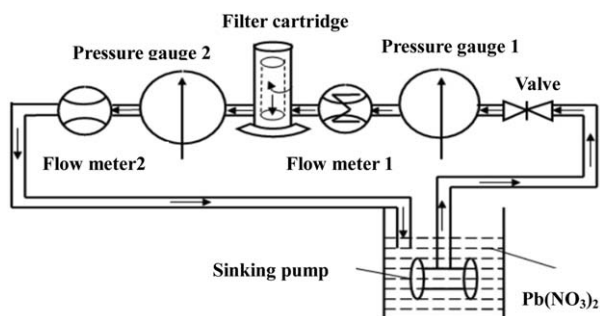


Figure 4. Schematic figure of the dynamic adsorption testing equipment.

$<0.01 \text{ mg L}^{-1}$. The sample solutions were treated with 5% HNO_3 to dissolve all particles.

Scanning Electron Microscopy (SEM). Surface of feather fibers before and after $\text{Na}_2\text{S}_2\text{O}_5$ modification were observed by using Japan JSM-5600LV scanning electronic microscope (SEM). The surface of samples were spurred with gold and observed under 15 kV.

Fourier Transform Infrared (FTIR) Spectroscopy Analysis. Attenuated total reflection infrared spectral technique was used to investigate the surface structure of samples. Duck feather fibers before and after $\text{Na}_2\text{S}_2\text{O}_5$ modification were tested with Nicolet NEXUS670 infrared-Raman spectroscopy tester. The wavenumber was $500\text{--}4000 \text{ cm}^{-1}$, the resolution was 4 cm^{-1} and the scan number was 10.

RESULTS AND DISCUSSION

Influence of $\text{Na}_2\text{S}_2\text{O}_5$ Treatment on Pb^{2+} Adsorption of the Feather Fiber

Urea is a kind of protein denaturant. It is often used together with $\text{Na}_2\text{S}_2\text{O}_5$ to modify protein.¹⁷ In this article, the feather fiber was treated by $\text{Na}_2\text{S}_2\text{O}_5$ under a series of concentrations ($0.026\text{--}0.395 \text{ M}$), while the concentration of urea remained unchanged. The Pb^{2+} adsorption capacity of modified feather fibers is shown in Figure 5.

It can be seen from Figure 5 that Pb^{2+} adsorption capacity of the feather fiber increased with increase in the concentration of $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution and reached the highest value when the concentration of $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution was 0.079 M . The Pb^{2+} adsorption capacity of raw feather fiber was 6.11 mg g^{-1} , while the highest Pb^{2+} adsorption capacity of modified feather fiber was 11.16 mg g^{-1} , over 80% higher than that of the raw feather fiber. Then the Pb^{2+} adsorption capacity of the feather fiber decreased a little and was kept unchanged with the increase of $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution concentration.

Structural Changes of the Feather Fiber Before and After $\text{Na}_2\text{S}_2\text{O}_5$ Modification

To uncover the reason why Pb^{2+} adsorption capacity of the feather fiber was improved after $\text{Na}_2\text{S}_2\text{O}_5$ modification, surface structure and secondary morphology of the feather fiber before and after $\text{Na}_2\text{S}_2\text{O}_5$ modification were investigated by SEM and FTIR and the results are shown in Figures 6–8, respectively.

It can be seen from Figure 6 that the sub-branch of the feather fiber carried a number of fibrils, which showed knars or pinacu-

lums around the surface. Rough grooves appeared on the surface of the sub-branches of the feather fiber. After $\text{Na}_2\text{S}_2\text{O}_5$ modification, the surface of sub-branches of the feather fiber became smooth and the feather fiber became thinner. It is hypothesized that keratin fragments scaled off from the feather fiber surface layer when it was treated by $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution, which was also observed by Sun et al.¹⁸ when the feather fiber was treated by NaOH solution.

The two primary bands of IR spectra of proteins are $1600\text{--}1700 \text{ cm}^{-1}$ for amide I and $1500\text{--}1560 \text{ cm}^{-1}$ for amide II, which arise from specific stretching and bending vibrations of the protein backbone.^{19,20} All of the secondary structures of proteins (α helix, β -sheet, and random-coil) have characteristic bands at amide I and amide II. For chicken feather fiber protein, the amide I and amide II bands appear at around 1640 and 1530 cm^{-1} , respectively.^{5,18,21} It can be seen from Figure 8 that the two spectra were identical to each other and the characteristic bands of α helix and β -sheet secondary structures of the duck feather fiber before and after $\text{Na}_2\text{S}_2\text{O}_5$ modification were all observed at 1630 and 1540 cm^{-1} in FTIR spectra, respectively. As we know, the band at 1450 cm^{-1} is the characteristic band of the main chain of feather fibers and can be used as the benchmark to relatively compare the band intensity of α helix and β -sheet structure. Hence, the band intensity of 1450 cm^{-1} is fixed to the same for all the samples, then the band intensity of α helix is subtracted from the band intensity of β -sheet, and the differences are listed in Table II.

It can be found from Table II that the difference in the band intensity of the two characteristic bands became more noticeable for the feather fiber after $\text{Na}_2\text{S}_2\text{O}_5$ modification. In other words, it seems that more α helix structure appeared after the feather fiber was modified by $\text{Na}_2\text{S}_2\text{O}_5$. Compared to β -sheet, α helix is more loose structure of the feather proteins, in which more hydrogen and/or disulfide bonds of feather keratin were broken during $\text{Na}_2\text{S}_2\text{O}_5$ modification. Hence more adsorptive sites are available for Pb^{2+} and the adsorption capacity of the feather fiber was improved after $\text{Na}_2\text{S}_2\text{O}_5$ treatment.

In addition, it is reported that the bands at 1079 and 1117 cm^{-1} arise from specific stretching and bending vibrations

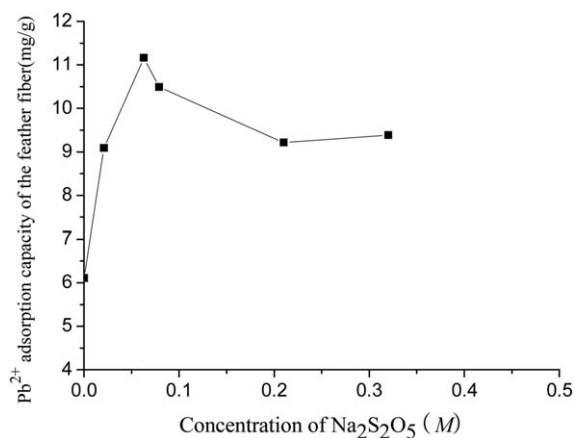
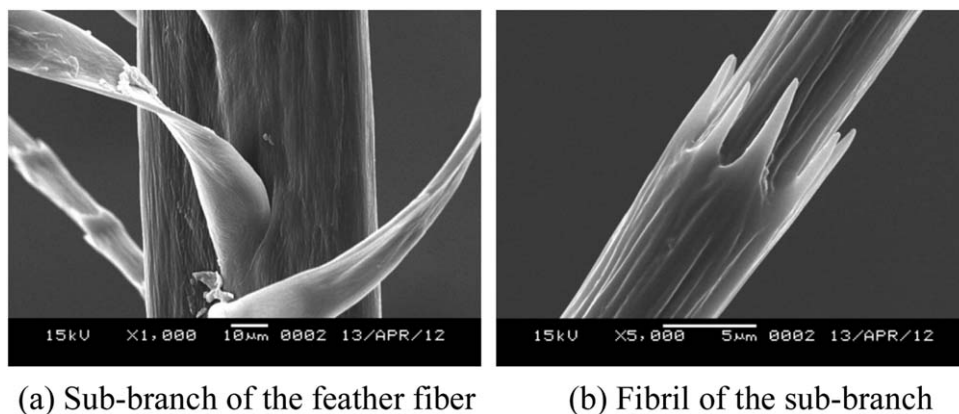


Figure 5. Influence of $\text{Na}_2\text{S}_2\text{O}_5$ treatment on Pb^{2+} adsorption of the feather fiber.



(a) Sub-branch of the feather fiber

(b) Fibril of the sub-branch

Figure 6. SEM picture of the raw feather fiber.

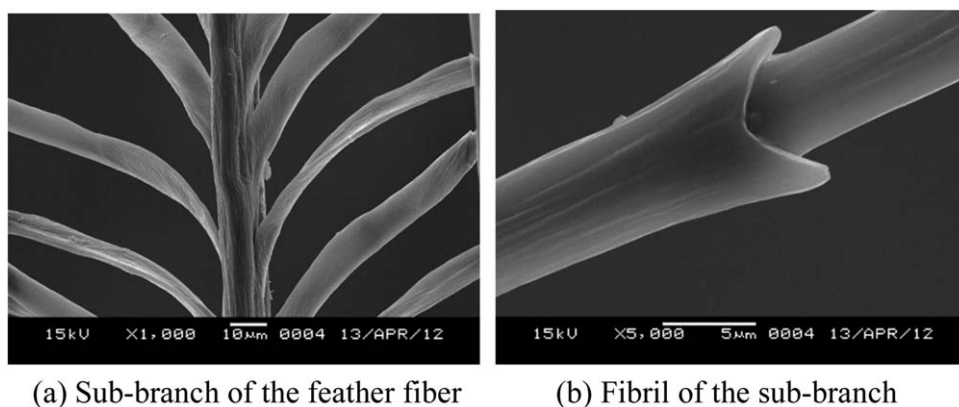
of S—O bond of cysteine, resulting from the broken disulfide bond of cysteine.²⁰ However, the spectra of feather fibers with and without $\text{Na}_2\text{S}_2\text{O}_5$ modification were identical in the frequency range, suggesting that $\text{Na}_2\text{S}_2\text{O}_5$ modification did not change the chemical structure of feather fibers to a detectable extent by FTIR spectroscopy. Perhaps $\text{Na}_2\text{S}_2\text{O}_5$ modification only changed hydrogen bonds of feather keratin. More hydrogen bonds of feather keratin were broken with the increase in the concentration of $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution. However, only a fraction of hydrogen bonds of feather keratin can be broken by $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solutions because of the constraint of disulfide bond. Hence it can be found from Figure 5 that Pb^{2+} adsorption capacity of the feather fiber increased with increase in the concentration of $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution and reached the highest value when the concentration of $\text{Na}_2\text{S}_2\text{O}_5$ aqueous solution was 0.079 M.

Desorption Effects of $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ and NaOH Solutions on the Feather Fiber

One of the advantages of the adsorption method is that the adsorbent can be regenerated and used repeatedly. In other words, the adsorbent should be desorbed. The desorption process for the recovery of metals is based on several mechanisms. Basically, there are three desorption mechanisms²²: (i) Precipitation of the metal adsorbed by formation of insoluble compounds with the desorbent agent, e.g. H_2S . (ii) Complexation of the metal adsorbed by reaction with compounds which have

pairs of electrons available to share with the metal cation. Desorbent agents such as ethylene diamine tetraacetic acid follow this mechanism. (iii) Ion exchange. Among them, ion-exchange method gives good yields by exchanging a cation from the desorbent reagents for the metal adsorbed. It is not convenient and safe to prepare H_2S in the lab. In this article, sodium sulfide ($\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$)²³ and NaOH²⁴ were used as desorption reagents for feather fibers and their desorption properties of Pb^{2+} ions from feather fibers are shown in Table III.

It can be seen from Table III that $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ showed quite low Pb^{2+} desorption capacity and its desorption effect did not change obviously with the increase of the concentration of desorbent solutions. Only about 1.3% Pb^{2+} of the feather fiber was desorbed by $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$. The desorption capacity of NaOH is 24–31% of the adsorption capacity of raw feather fibers, which is 6.11 mg g^{-1} as shown in Figure 5. It is hypothesized that $\text{Pb}(\text{OH})_2$ and PbS would form, when the Pb^{2+} adsorbed-feather fiber was immersed in NaOH and $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ aqueous solution, respectively. The solubility product constant of $\text{Pb}(\text{OH})_2$ is 1.43×10^{-20} , which is much higher than that of PbS (3.4×10^{-28}). Hence more PbS deposit should be formed. However, it was found that the feather fiber changed color obviously and became nearly broken up when the concentration of $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ aqueous solution was as high as 0.03 M, suggesting that $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ preferentially involved in the reaction with keratin of the feather fiber rather than with Pb^{2+} ion. Hence



(a) Sub-branch of the feather fiber

(b) Fibril of the sub-branch

Figure 7. SEM picture of the feather fiber after $\text{Na}_2\text{S}_2\text{O}_5$ modification.

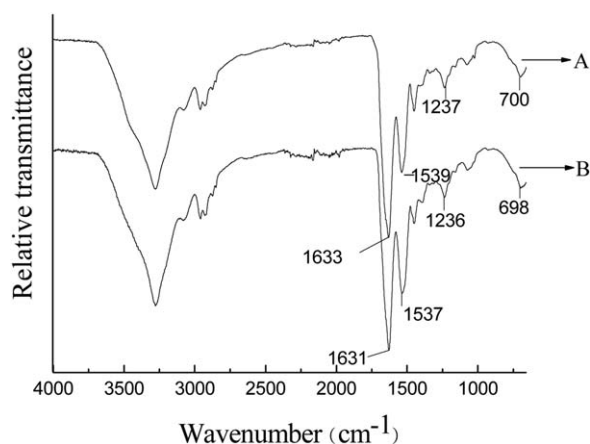


Figure 8. FTIR spectra of the feather fiber before and after $\text{Na}_2\text{S}_2\text{O}_5$ modification (A—raw feather fiber; B—feather fiber after $\text{Na}_2\text{S}_2\text{O}_5$ modification).

NaOH showed better desorption effect than $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$. In addition, the desorption capacity of NaOH did not change obviously when its concentration was increased to 0.05 M. It is reported that complex ions, such as $[\text{Pb}(\text{OH})_4]^{2-}$, $\text{Pb}_4(\text{OH})_4^{4+}$, $\text{Pb}_3(\text{OH})_4^{2+}$, and $\text{Pb}_6(\text{OH})_6^{4+}$ will be formed when the pH value is higher than 9. $\text{Pb}(\text{OH})_2$ deposit will be re-dissolved correspondingly.

To further investigate the desorption effect of NaOH, duck feather fibers were treated by adsorption and desorption experiment for 12 times. The Pb^{2+} adsorption capacity of feather fibers after each desorption cycle is shown in Figure 9 and the Pb^{2+} removal of feather fibers in every cycle is shown in Figure 10.

It can be found from Figure 9 that Pb^{2+} adsorption capacity of the NaOH treated feather fibers increased with the increase of the desorption cycles and decreased slightly when the desorption time was higher than 6. As we know, the secondary structure of feather keratin mainly contains random-coil, α helix, and β -sheet. Compared to β -sheet, α helix is a more loose structure of feather keratin, with more adsorptive sites available for metal ions. It is reported that β -sheet was transferred into α -helix when feather fibers were treated by alkali solution.¹² With the increase of desorption cycle, more β -sheet was transferred into α -helix. Hence the Pb^{2+} adsorption capacity of feather fibers increased with the increase of desorption cycles. However, when the desorption cycle was higher than 6, there was less β -sheet transition. Hence the Pb^{2+} adsorption capacity of the NaOH treated feather fibers decreased slightly.

Table II. Difference in Peak Intensity of α and β Structures of Modified Feather Fibers

	Y_{1630}	Y_{1540}	$Y_{\beta} - Y_{\alpha}$
Raw feather fiber	42.3	66.8	24.5
$\text{Na}_2\text{S}_2\text{O}_5$ modified feather fiber	67.9	94.7	26.8

Y_{1630} and Y_{1540} represent the infrared transmittance of the bands at 1630 cm^{-1} and 1540 cm^{-1} , respectively.

Table III. Desorption Properties of NaOH and $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ Solutions on Feather Fibers

Concentration of desorbent (M)	0.01	0.02	0.03	0.05
Desorption capacity of NaOH (mg g^{-1})	1.46	1.58	1.89	1.86
Desorption capacity of $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$ (mg g^{-1})	0.02	0.04	0.08	-

Accordingly, it can be found from Figure 10 that Pb^{2+} removal of the NaOH treated feather fibers increased with the increase of the desorption cycles and decreased slightly when the desorption time was higher than 6. Although the Pb^{2+} removal of the NaOH treated feather fibers at the first cycle is only 24–31% of the adsorption capacity of raw feather fibers, because of the contribution of increasing Pb^{2+} adsorption capacity of feather fibers after NaOH treatment, Pb^{2+} removal of feather fibers increased with the increase of the desorption cycles at first and then decreased when the desorption time was higher than 6, as shown in Figure 10.

Dynamic Pb^{2+} Adsorption Properties of Feather/PP Melt-Blown Filter Cartridges

In this article, the feather fibers with and without $\text{Na}_2\text{S}_2\text{O}_5$ modification were made into feather/PP and modified feather/PP melt-blown filter cartridge according to the patent titled a kind of feather/polypropylene composite melt-blown filter cartridge and its process.²⁵ It is found that the feather fiber could be easily bonded to each other by PP melt-blown nonwoven fibers and the filter cartridges had good physical and mechanical properties. In addition, the dynamic Pb^{2+} adsorption properties of the three kinds of filter cartridges as listed in Table I were measured by using the test equipment set up in our lab. The dynamic adsorption properties of three kinds of filter cartridges are shown in Figure 11, in which y axis represents the Pb^{2+} concentration of the solution in the cycling reservoir.

It is found from Figure 11 that modified feather/PP filter cartridge had highest Pb^{2+} adsorption capacity than feather/PP filter cartridge and pure PP filter cartridge in the whole dynamic

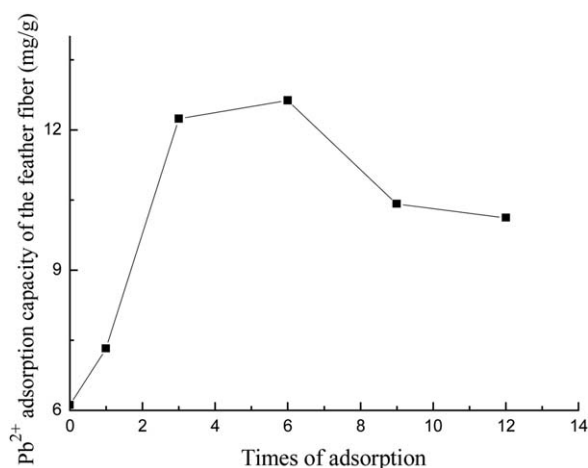


Figure 9. Repeated Pb^{2+} adsorption capacity of feather fibers.

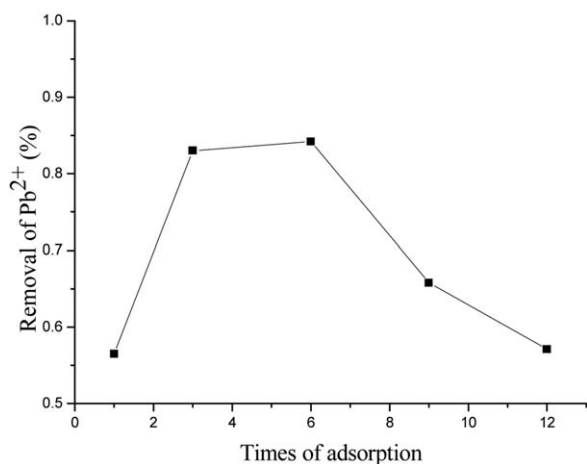


Figure 10. Pb²⁺ removal of feather fibers in every cycle.

adsorption process measured in this article. In addition, the Pb²⁺ adsorption capacity of pure PP filter cartridge was a little lower than that of feather/PP filter cartridge. As shown above, the Pb²⁺ uptake capacity of raw feather fibers is about 6.11 mg g⁻¹. It is reported that the Pb²⁺ adsorption capacity of PP strip is about 0.1 mg g⁻¹,²⁶ which is much lower than that of feather fibers. It is believed that PP fibers of these two kinds of filter cartridges have higher specific surface area, resulting in higher Pb²⁺ uptake capacity than that of PP strip. When modified feather/PP filter cartridge was used as the filter cartridge, Pb²⁺ concentration in the solution decreased fastest in the first hour in comparison with the other two filter cartridges, suggesting that modified feather/PP filter cartridge had fastest Pb²⁺ adsorption speed in the initial dynamic Pb²⁺ adsorption process. In the third hour of the dynamic adsorption process, the residual Pb²⁺ in the solution was about 0.09 M. Based on the assumption that melt-blown filter cartridge is widely used as liquid filtration material, modified feather/PP melt-blown filter cartridge is a promising material, exhibiting filtration and Pb²⁺ adsorption functions at the same time.

CONCLUSIONS

The adsorption and desorption properties of modified feather and feather/PP melt-blown filter cartridge of Pb²⁺ were studied

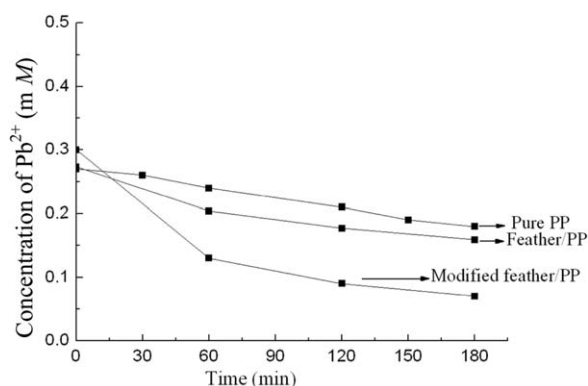


Figure 11. Dynamic adsorption properties of three kinds of filter cartridges.

in this article. First, it is concluded that Pb²⁺ adsorption capacity of the feather fiber increases after being modified by Na₂S₂O₅. The highest Pb²⁺ adsorption capacity of the modified feather fiber is over 80% higher than that of the raw feather fiber; second, NaOH is an effective desorbent agent for the Pb²⁺ loaded feather fibers; third, Na₂S·9H₂O did not show expected Pb²⁺ desorption effect. It involved in the reaction with feather keratin desorber rather than with Pb²⁺ during the desorption experiment. Finally, modified feather/PP filter cartridge has higher Pb²⁺ adsorption capacity than feather/PP filter cartridge and pure PP filter cartridge in the whole dynamic adsorption process.

Na₂S₂O₅ treated feather/PP melt-blown filter cartridge is a kind of promising material for wastewater effluent treatment. But more work should be done to test the long-term filtration performance and the desorption properties of the Na₂S₂O₅ treated feather/PP melt-blown filter cartridge prepared in this article.

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REFERENCES

- Gupta, V. K.; Carrott, P. J. M.; Ribeiro Carrott, M. M. L.; Suhas. *Crit. Rev. Environ. Sci. Technol.* **2009**, *39*, 783.
- Rashed, M. N. *Environmentalist* **2001**, *21*, 187.
- Lezcano, J. M.; González, F.; Ballester, A.; Blázquez, M. L.; Muñoz, J. A.; García Balboa, C. *J. Environ. Manage.* **2011**, *92*, 2666.
- Gao, J.; Yu, W.; Pan, N. Structures and properties of the goose down as a material for thermal insulation. *Text. Res. J.* **2007**, *8*, 617.
- Sun, P.; Liu, Z.; Liu, Z. *J. Hazard. Mater.* **2009**, *170*, 786.
- De la Rosa, G.; Reynel-Avila, H. E.; Bonilla-Petriciolet, A.; Cano-Rodriguez, I.; Velasco-Santos, C.; Martinez-Hernandez, A. L. *Int. J. Chem. Biomol. Eng.* **2008**, *1*, 185.
- Kyozo, S. *J. Appl. Biochem. Biotechnol.* **1996**, *57*, 67.
- Al-Asheh, S.; Banat, F.; Al-Rousan, D. *Adsorpt. Sci. Technol.* **2002**, *20*, 849.
- Banat, F.; Al-Asheh, S. *Environ. Eng. Policy* **2000**, *1*, 85.
- Banat, F.; Al-Asheh, S.; Al-Rousan, D. *Adsorpt. Sci. Technol.* **2002**, *20*, 393.
- Al-Asheh, S.; Banat, F.; Al-Rousan, D. *J. Clean Prod.* **2003**, *11*, 321.
- Jin, X. Y.; Lu, L.; Wu, H. B.; Wang, H. *J. Eng. Fiber Fabr.* **2013**, *8*, 21.
- Moore, G. R. P.; Martellia, S. M.; Gandolfo, C.; Amaral Sobral, P. J.; Laurindo, J. B. *Food Hydrocol.* **2006**, *20*, 975.
- Wang, J.; Liu, J. *Wool Text. J.* **2011**, *8*, 59.

15. Kar, P.; Misra, M. *J. Chem. Technol. Biotechnol.* **2004**, *79*, 1313.
16. Aguayo-Villarreal, I. A.; Bonilla-Petriciolet, A.; Hernández-Montoya, V.; Montes-Morán, M.; Reynel-Avila, H. E. *Chem. Eng. J.* **2011**, *167*, 67.
17. Gou, M.; Yang, X.; Meng, G. *Wool Spinning Technol.* **2011**, *3*, 18.
18. Sun, P.; Liu, Z.; Liu, Z. *Ind. Eng. Chem. Res.* **2009**, *48*, 6882.
19. Martínez-Hernández, A. L.; Velasco-Santos, C.; De Icaza, M.; Castao, V. M. *Int. J. Environ. Pollut.* **2005**, *23*, 162.
20. Yang, C. L.; Wu, Z. W.; Wang, Q.; Wang, M. *J. Zhongyuan. Univ. Technol.* **2010**, *21*, 55.
21. Wang, H.; Shao, H. L.; Hu, X. C. *J. Appl. Polym. Sci.* **2006**, *101*, 961.
22. Tarawou, T.; Wankasi, D.; Horsfall, M., Jr. *J. Environ. Sci. Eng.* **2010**, *4*, 38.
23. Sun, W.; Zhang, G.; Dong, Y.; Li, C. *Nonferrous Met.* **2011**, *2*, 52.
24. Zhao, Y. Q.; Yue, Q. Y.; Li, Q. *J. Hazard. Mater.* **2010**, *182*, 309.
25. Wang, H.; Ding, X. F.; Jin, X. Y.; Wu, H. B. Patent Application 201210019962.2, China, **2012**.
26. Motsa, M. M.; Thwala, J. M.; Msagati, T. A. M.; Mamba, B. *Phys. Chem. Earth* **2011**, *36*, 1178.