

# Preparation of Cellulosic Ion Exchange Fiber Using an Ionic Liquid as Reaction Reagent and Medium

Chunming Chen, Chi Yang

Department of Chemistry, Hanshan Normal University, Chaozhou 521041, China

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**ABSTRACT:** A cellulosic ion exchange fiber (CIEF) was prepared by using room-temperature ionic liquid 1-(3-chloro-2-hydroxypropyl)-3-methylimidazolium chloride as reaction reagent and medium. The results showed the degree of substitution of the CIEF was up to 0.78. The product was characterized by Fourier transform infrared spectrometry, thermogravimetric analysis, scanning electronic microscope. The thermal stability of the CIEF was

over 200°C. The adsorption experiments of CIEF for Cr(VI) were performed. The adsorption capacity of CIEF for Cr(VI) was found to be 196.1 mg g<sup>-1</sup> at 30°C. © 2011 Wiley Periodicals, Inc. *J Appl Polym Sci* 122: 2287–2294, 2011

**Key words:** ion exchanger; fibers; adsorption; biopolymers; degree of polymerization

## INTRODUCTION

Draining of heavy metals and organic substance are increasing daily with the rapid development of industries and the use of chemical substances in many industries. The survival environment of human being and other creatures have been threatened by heavy metal ions and organic substance pollution, which has become the most serious problem. A good and cheap adsorbent, which are both environmental friend is needed.<sup>1,2</sup> Compared with the tradition ion exchange resin, the ion exchange fiber has many excellent properties, such as big efficient surface area, rapid sorption rate, different fabric forms for various uses, and well recyclability. This kind of functional fiber has been prepared and successfully used in the purifying of waste gas and water-containing toxic impurities, and the beneficiation of some precious metal ions.<sup>3–6</sup>

Cellulose is the most abundant biopolymer in the nature and widely used as a raw material in numerous industrial applications. The potential advantages of such biobased materials are low cost, not depending on petroleum sources, available from renewable resources, and enabling to replace some synthetic polymers, and so forth.<sup>7,8</sup> Chemical modification of cellulose, introducing functional groups into the

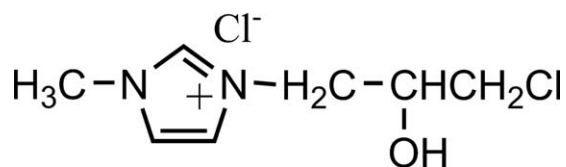
macromolecules to substitute the free hydroxyl groups in heterogeneous phase or homogeneous phase is one of the methods for the production of the ion exchange fibers.<sup>9–12</sup> Homogeneous functionalization has been a focus of cellulose research for a long time, because more uniform and stable products could be obtained. However, due to the stiff molecule and close chain packing via numerous intermolecular and intramolecular hydrogen bonds, cellulose is extremely difficult to dissolve in water and most of the traditional organic solvents, which is a major obstacle for cellulose homogeneous modification. Suitable cellulose solvents, which can efficiently dissolve cellulose and provide feasible reaction environment for cellulose functionalization, are eagerly needed in cellulose utilization.<sup>13–15</sup> To date, only a limited number of solvent systems have been found, for example, dimethylacetamide (DMAc)/LiCl, 4-methylmorpholine-*N*-oxide (NMNO), *N,N*-dimethylformamide (DMF)/N<sub>2</sub>O<sub>4</sub>, and dimethyl sulfoxide (DMSO)/tetrabutylammonium fluoride (TBAF) and some molten salt hydrates, such as LiClO<sub>4</sub>·3H<sub>2</sub>O, and LiSCN·2H<sub>2</sub>O.<sup>16</sup> However, the limitations such as toxicity, cost, and difficulty for solvent recovery are still great challenge for their industrial application.

Room-temperature ionic liquids (ILs), which being considered as desirable green solvents and reaction media for a wide range of processes have recently received significant attentions.<sup>17–23</sup> In 2002, dissolution of cellulose with ILs was first reported by Swatoski et al.<sup>24</sup> It was found that cellulose can easily dissolve in 1-butyl-3-methylimidazolium chloride in high concentration. In 2005, a ILs, 1-allyl-3-methylimidazolium chloride was synthesized and used to carry out homogeneous modification of cellulose.<sup>25</sup>

Correspondence to: C. Chen (ccming2003@163.com).

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**Scheme 1** The chemical structure of ChmimCl.

Recently, a novel ILs, 1-(3-chloro-2-hydroxypropyl)-3-methylimidazolium chloride (ChmimCl) was synthesized in our lab with outstanding capabilities for dissolving cellulose. The chemical structure of ChmimCl is shown in Scheme 1. ChmimCl is a fine solvent for cellulose. Interestingly, it is able to act as a reaction reagent for chemical modification of cellulose containing an appended 3-chloro-2-hydroxypropyl functionality group.<sup>26</sup>

In this article, the homogeneous modification of cellulose to produce ion exchange fibers was studied, by using ChmimCl as the solvent and reaction reagent for chemical modification of cellulose. Homogeneous modification conditions of cellulose in ChmimCl, including reaction temperature and reaction time, were investigated. The degree of substitution (DS) of cellulose derivatives was measured by titration method. The physicochemical properties of the ion exchange fibers were investigated in terms of Fourier transform infrared spectrometry (FTIR), thermogravimetric analyzer (TGA), powder X-ray diffraction, scanning electronic microscope (SEM), and atomic absorption spectroscopy. The adsorption experiments of the ion exchanger for Cr(VI) ions were studied.

## EXPERIMENTAL

### Materials

Absorbent cotton was purchased from Shanghai Experiment Reagent, China, and was selected as the cellulose sample. N-methyl imidazole (Aldric) and epichlorohydrin (Fluka) were used without further purification. All other chemical reagents were purchased from commercial resources in China and were of reagent grade.

### Synthesis of the IL ChmimCl

The IL, ChmimCl was synthesized as described in our previous work [26]. Briefly, 100-mL ethanol and hydrochloric acid (17.0 mL, 200 mmol, 36% in weight) was placed in a flask equipped with a reflux condenser and a dropping funnel. N-methyl imidazole (15.8 mL, 200 mmol) was added dropwise to the flask in about 45 mins, adjusted the solution with the excessive hydrochloric acid to pH 6 ~ 6.5, epichlorohydrin (15.7 mL, 220 mmol) was dropped

slowly into the above aqueous solution at 5°C under the agitation. After all epichlorohydrin was dropped, the temperature of the mixed solution was raised to 45°C, the reaction time was maintained for 3 h. The light yellow viscous liquid, 1-(3-chloro-2-hydroxypropyl)-3-methyl imidazolium chloride, was obtained through removing water, ethanol, and remanent epichlorohydrin by means of the reduced pressure distillation. The ILs was reused four times after treated by ultrasonic extraction with ether, and the resulting ILs was passed through the columns with active carbon, silica gel-G60, and neutral alumina. The ILs was dried in vacuum drying oven at 60°C. ChmimCl <sup>1</sup>H NMR (250 MHz, DMSO-*d*<sub>6</sub>, δ): 9.09 (s, 1H, ring C(2)H), 7.79–7.54 (dd, 2H, ring C(4,5)H), 5.33 (s, 1H, OH), 4.12 (1H, CH—O), 3.85 (m, 2H, CH<sub>2</sub>-N<sub>ring</sub>), 3.8 (s, 3H, CH<sub>3</sub>-N<sub>ring</sub>), 3.7 (2H, CH<sub>2</sub>-Cl). The constitutional formula was shown in Scheme 1, and the process was shown in Scheme 2.

### Preparation of cellulosic ion exchange fiber

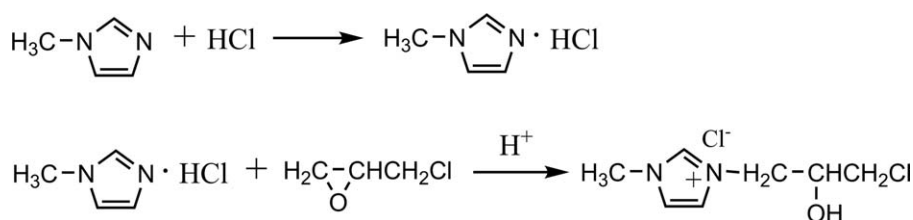
Absorbent cotton (0.6 g) was pretreated with 20% aqueous sodium hydroxide solution for 2 h at room temperature and vacuum dried at 30 mmHg, at 70°C for 4 h before use. The cellulose was dispersed into ChmimCl (14.4 g, 13.8 mL), and the mixture of cellulose/ChmimCl was stirred at 60°C for 4 h to guarantee the complete dissolution. The resultant solutions were slowly poured into 300 mL of ethanol with stirring to stop the reaction. The solid was filtered, washed thoroughly with ethanol to eliminate ILs. Suspend it in 50.0-mL 1.0M aqueous sodium hydroxide solution, 0.5-mL epichlorohydrin was added, and the suspension was left for 24 h at room temperature under magnetic stirring. After washing with a large amount of distilled water to neutral, and dried in vacuum at 70°C for about 12 h. The cellulosic ion exchange fiber (CIEF) with cationic groups was obtained. At the end of each experiment, the IL ChmimCl was recycled by evaporating the filtrate. The process was shown in Scheme 3.

### Determination of the degree of substitution

The DS of CIEF was calculated from the chloride analysis (DS<sub>Cl</sub>) according to the following equation:

$$DS_{Cl} = \frac{162 \times Cl\%}{35.5 \times 100 - 174.5 \times Cl\%}$$

where Cl% is the percentage of Cl in the sample, 162 g mol<sup>-1</sup> is the molar mass of an anhydroglucose units in cellulose were studied, 174.5 g mol<sup>-1</sup> is the net increase in the mass of an anhydroglucose units for each ChmimCl cationic group substituted, and 35.5 g mol<sup>-1</sup> is the molar mass of chloride atom.<sup>16</sup>



Scheme 2 The outline of the synthesis of the IL ChmimCl.

### Characterization

The IR spectra of the cellulose and CIEF samples were recorded with a FTIR spectrometer (6700, NICOLET). The test specimens were prepared by the KBr-disk method. The morphologies of the cellulose and CIEF samples were measured by a JSM-6360LA SEM. The free surface was sputtered with gold, and TGA was performed on NETZSCHSTA 449C. Samples were heated from room temperature to 800°C, at a heating rate of 10°C min<sup>-1</sup> under nitrogen atmosphere.

### Adsorption experiments

Adsorption experiments were conducted in closed 100-mL Erlenmeyer flasks. For each experiment, 0.1 g of CIEF was shaken with 50 mL of potassium dichromate solution of a specified Cr(VI) ion concentration inside a water bath shaker operating at 200 rpm at 30°C. The pH of the solution was adjusted to a defined value with 0.1M HCl or 0.1M NaOH. At the end of the desired time, the mixture in each flask was centrifuged, and the Cr(VI) concentration in the supernatant solution was determined by using of a Hitachi Z-2000 flame atomic absorption spectrometer (AAS). The amount of Cr(VI) adsorbed was calculated by the difference between the initial concentrations and the final concentrations.

The influence of the pH on Cr(VI) sorption was studied by using Cr(VI) solutions with initial concentrations 50.0 mg L<sup>-1</sup>, which in the pH range 2.0–9.0 at 30°C. The initial pH of the solution was adjusted with 0.1M HCl or 0.1M NaOH.

A sorption isotherm  $c_e$  versus  $q_e$  was drawn by conducting sorption experiments at different initial concentrations of Cr(VI) ranging from 100 to 600 mg L<sup>-1</sup> at 30°C, which was calculated by the equation:

$q_e = (c_0 - c_e)V/m$ , where  $q_e$  is the adsorption capacity of the CIEF,  $c_0$  and  $c_e$  are the initial and equilibrium concentrations,  $V$  is the volume of potassium dichromate solution, 50 mL,  $m$  is the mass of the CIEF, 0.1 g.

Adsorption kinetics was measured at the optimum pH with different Cr(VI) concentrations ranging from 100 to 400 mg L<sup>-1</sup> at 30°C. Potassium dichromate solutions (50 mL) with different Cr(VI) concentrations were, respectively, added in four Erlenmeyer flasks with 0.1 g of CIEF and shaken for different given times. The concentration of Cr(VI) was determined with AAS to calculate the adsorption capacity ( $q_e$ ) at this time, then the adsorption rate curve was drawn.

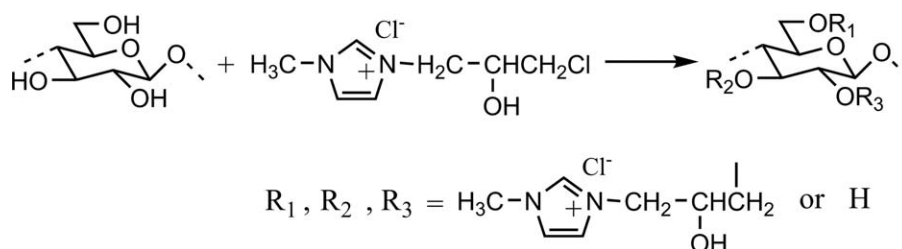
### Desorption experiments

The reusability of CIEF was tested by shaking the spent CIEF in 1.0M HCl for a period of 4 h. After equilibrium had been achieved, the suspension was centrifuged, and the supernatant collected after each desorption was analyzed by using the AAS for the Cr(VI) concentration. The desorbed Cr(VI) concentration was estimated. To reuse the CIEF, following the desorption, the spent CIEF was washed with distilled water before the second Cr(VI) adsorption process. The adsorption and desorption processes were repeated for four cycles. The experiments were performed at 30°C.

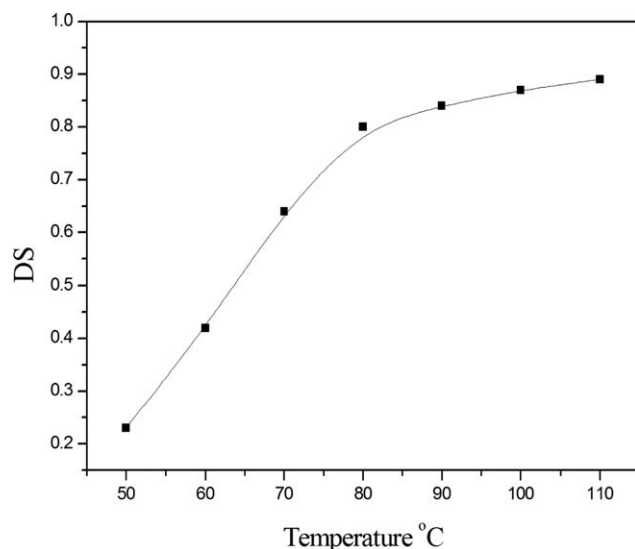
## RESULTS AND DISCUSSIONS

### Dissolution of cellulose sample in ChmimCl

In our previous study, it is shown that the cellulose samples, such as microcrystalline cellulose, wood pulp, and cotton linters, can be lightly dissolved in



Scheme 3 The outline of the synthesis of cellulosic ion exchange fiber.



**Figure 1** Effect of reaction temperature on DS for cellulosic ion exchange fiber.

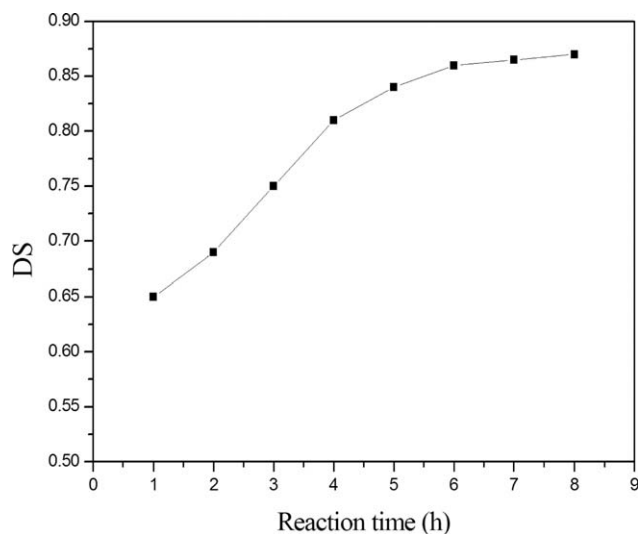
the ChmimCl. Solubility of cellulose is 11.0 g/100 g of ChmimCl at 100°C, the advantage is attributed to the hydroxyl-rich microenvironment. In this study, the ChmimCl was used as solvent and reaction reagent for grafting modification of cellulose to product ion exchange fibers. In a typical procedure of cellulose/ChmimCl solution, 0.8 g cellulose sample was dispersed into ChmimCl (15.2 g, 14.5 mL), and the mixture was stirred at 100°C for 4 h, a transparent cellulose solution with about 5 wt % concentration was obtained.

#### Effect of reaction temperature on DS

To optimize the reaction temperature for higher DS, the effect of reaction temperature on the DS was investigated at different temperatures, where the reaction time (4 h) was constant. The results are shown in Figure 1. The reaction temperature has a great effect on the graft modification. A CIEF with a DS of 0.23 was obtained with the reaction temperature 50°C, and when the reaction temperature was 80°C, the DS of CIEF could reach to 0.80, but with further increasing reaction temperature to 110°C, the DS increased slightly to 0.87. It should be noticed that the increase of reaction temperature could result in an increment in DS values of CIEF.

#### Effect of reaction time on DS

The effect of reaction time on the DS was investigated at the reaction temperature of 100°C. The DS values of resultant CIEF were shown in Figure 2. It can be noticed that the DS first increased sharply with reaction time, and this increment became slightly after about 4 h. For example, a CIEF with a

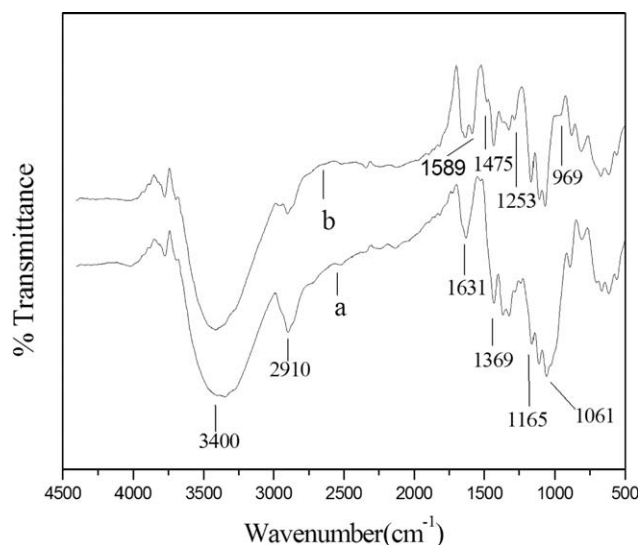


**Figure 2** Effect of reaction time on DS for cellulosic ion exchange fiber.

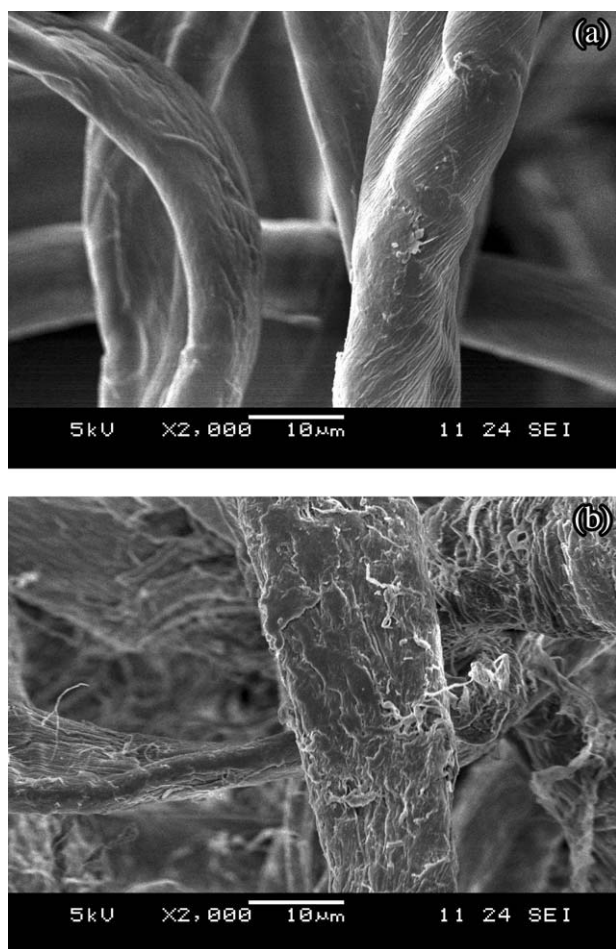
DS of 0.65 was obtained within only 1 h, and after 4 h of reaction time, the DS of CIEF could reach to 0.82, but with further increasing reaction time to 8 h, the DS increased slightly to 0.87.

#### FTIR analysis

The spectra of cellulose and the cellulosic ion exchange fiber were indicated in Figure 3. The absorbances at 3400, 2910, 1631, 1369, 1165, and 1061  $\text{cm}^{-1}$  seen in Figure 3(a) were associated with native cellulose. 3400  $\text{cm}^{-1}$ , could be attributable to OH stretching and bands of (intra- and inter-molecular) H bonds; 2910  $\text{cm}^{-1}$ , could be attributable to C—H asymmetric and symmetric stretching; 1631  $\text{cm}^{-1}$ ,



**Figure 3** FT-IR Spectrum of unmodified cellulose (a), and cellulosic ion exchange fiber (b).



**Figure 4** SEM images of (a) unmodified cellulose and (b) cellulosic ion exchange fiber.

could also correspond to  $\text{—O—}$  tensile vibration neighboring to H group;  $1369\text{ cm}^{-1}$ ,  $\text{CH}_2$  and OH bending;  $1165\text{ cm}^{-1}$ , C—O and C—O—C stretching; and  $1061\text{ cm}^{-1}$ , ring vibration and C—OH bending. In comparison, the spectrum of CIEF [Fig. 3(b)] provided evidence of imidazole cation. The bands at  $1589$  and  $1475\text{ cm}^{-1}$  corresponded to imidazole ring skeletal vibration. The absorption band at  $1253\text{ cm}^{-1}$  was assigned to the C—N stretching vibration. The peak at  $969\text{ cm}^{-1}$  attributed to out-of-plane C—H bending of imidazole ring.

### SEM observation

SEM is often used to image the surface morphological change before and after the modification. SEM images revealed a pronounced difference between the virgin and grafted cellulose fibers [Fig. 4(a,b)]. After the modification, the grafted fiber appeared rough surface with a large number of ion exchange channels. The surface of the CIEF is almost covered by functional group after the grafting process.

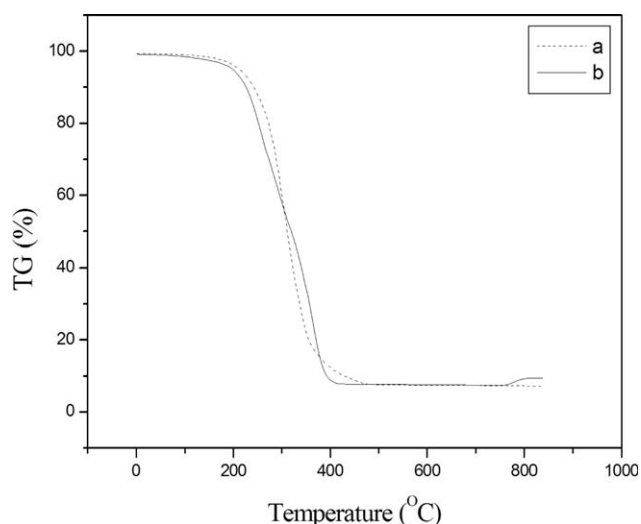
### Thermal analysis

The thermal behavior of unmodified cellulose and cellulosic ion exchange fiber was studied by TGA in  $\text{N}_2$  atmosphere. Figure 5 illustrated the TGA thermograms of unmodified cellulose [Fig. 5(a)] and cellulosic ion exchange fiber [Fig. 5(b)]. It can be clearly seen that unmodified cellulose began to decompose at  $246^\circ\text{C}$ , whereas the cellulosic ion exchange fiber began to decompose at  $214^\circ\text{C}$ . At 50% weight loss, the decomposition temperature occurred at  $326^\circ\text{C}$  for unmodified cellulose and  $330^\circ\text{C}$  for the cellulosic ion exchange fiber. This decreasing trend of decomposition temperature indicated that the thermal stability of the cellulosic ion exchange fiber was lower than that of the unmodified cellulose. However, the thermal stability of the cellulosic ion exchange fiber over  $200^\circ\text{C}$  was rather satisfactory to use as a biodegradable material for absorbing heavy metals from industrial wastewater.

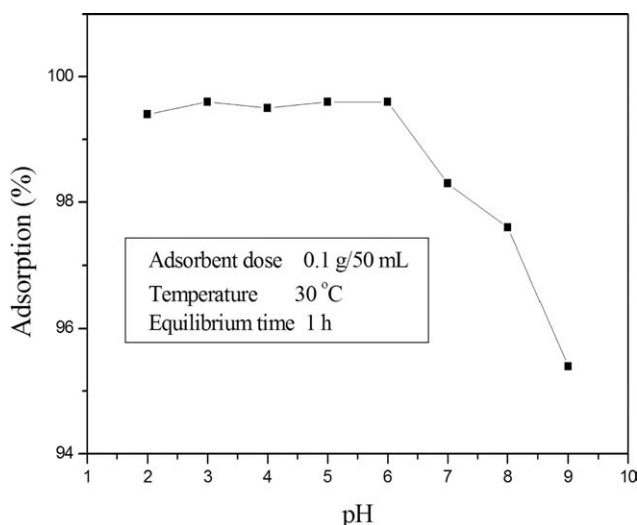
### The influence of the pH on Cr(VI) adsorption

The influence of the pH on the adsorption of Cr(VI) was examined over the pH range of 2.0–9.0 was shown in Figure 6. The maximum percentage removal of Cr(VI) by CIEF was obtained at the  $\text{pH} < 6.0$ , after that, the adsorption of Cr(VI) was decreased with increasing pH value. At  $\text{pH} 6.0$ , the extent of Cr(VI) removal by CIEF at initial concentrations of  $50\text{ mg L}^{-1}$  was 99.6% ( $24.9\text{ mg g}^{-1}$ ).

The effect of pH on the adsorption of Cr(VI) onto CIEF can be interpreted according to the surface charge of the adsorbent and the speciation of chromium. At pH values of  $< 6.0$ , the predominant Cr(VI) species mainly exists in the anion ( $\text{Cr}_2\text{O}_7^{2-}$ ) form, the  $\text{Cl}^-$  ions from the



**Figure 5** The thermograms of unmodified cellulose (a) and cellulosic ion exchange fiber (b).



**Figure 6** Effect of pH on the adsorption of Cr(VI) onto CIEF.

adsorbent exchange with anionic Cr(VI) species present in solution. The decrease in removal efficiency at higher pH values might be the higher concentration of OH<sup>-</sup> ions present in the reaction mixture, which competed with anionic Cr(VI) species for the adsorption sites.

### Adsorption isotherm

At 30°C, the relationship between the amount of Cr(VI) adsorbed per unit mass of adsorbent,  $q_e$  (mg g<sup>-1</sup>), and its final concentration in solution,  $C_e$  (mg L<sup>-1</sup>), was shown in Figure 7. It showed that the adsorption sharply increased up to an initial concentration of 400.0 mg L<sup>-1</sup>, which corresponded to an equilibrium concentration,  $C_e$ , of 20.0 mg L<sup>-1</sup>. This indicated that 95.0% of the Cr(VI) was removed from the solution in this region. Above this concentration, the adsorption approached a plateau value. The most common mathematical models for describing adsorption isotherms in aqueous solution are the Langmuir and Freundlich equations, which have the following forms

$$\text{Langmuir } \frac{C_e}{q_e} = \frac{1}{bq_m} + \frac{C_e}{q_m} \quad (2)$$

$$\text{Freundlich } \ln q_e = \ln k + \frac{1}{n} \ln C_e \quad (3)$$

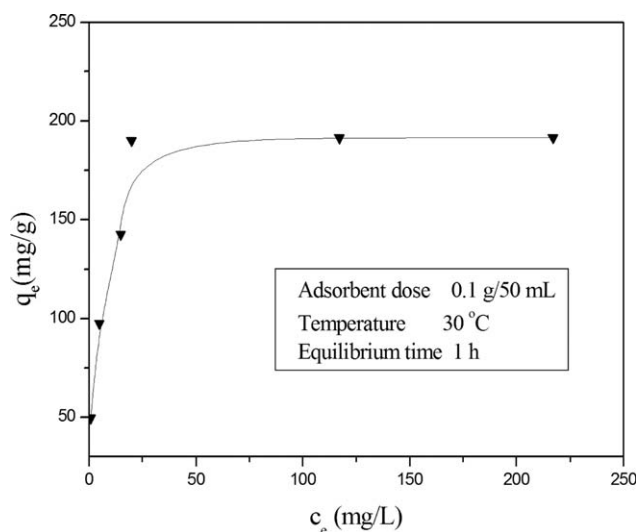
where  $q_m$  and  $b$  are Langmuir adsorption constants related to the adsorption capacity and the binding energy of adsorption, respectively, and  $k$  and  $n$  are the characteristic constants,  $k$  represents the relative adsorptive capacity, and  $n$  describes the heterogeneity of adsorbent surface and the relative adsorptive strength. The basic assumption of the Langmuir theory is that adsorption takes place at

specific homogeneous sites within the adsorbent, whereas the Freundlich isotherm is derived by assuming a heterogeneous surface with a nonuniform distribution of heat of adsorption over the surface. The experimental data for the equilibrium adsorption of Cr(VI) onto CIEF were fitted to the Langmuir and Freundlich isotherms. The isotherm constants were determined using nonlinear regression analysis. The values of  $R^2$  were found to be  $R^2 = 0.9995$  for Langmuir isotherm and  $R^2 = 0.8312$  for the Freundlich isotherm. Clearly, the Langmuir equation provided a better fitting in terms of  $R^2$  value. Figure 8(a,b) shows the comparative fit of Langmuir and Freundlich isotherm with the equilibrium data, and it is again clear from these figures that Langmuir linear regression curve reveals nicer linear correlation. The values of  $q_m$  and  $b$  for the adsorption of Cr(VI) onto CIEF were found to be 196.1 mg g<sup>-1</sup> and 0.304 L mg<sup>-1</sup>, respectively; the corresponding values of  $k$  and  $1/n$  were found to be 64.52 and 0.243, respectively, at 30°C.

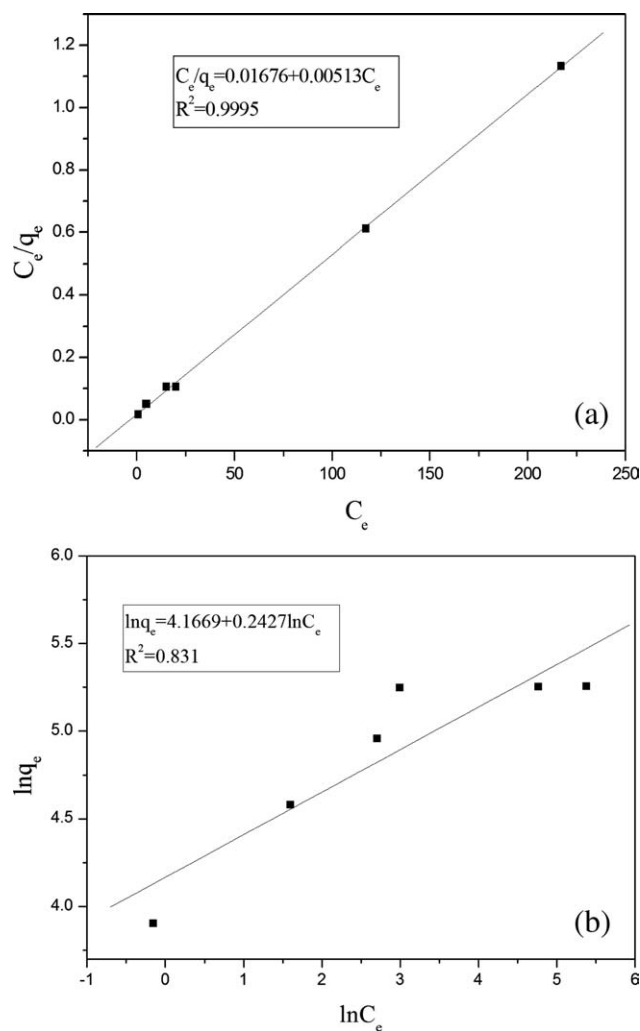
### Adsorption kinetics

The variation of the adsorption capacity ( $q_e$ ) with increasing time ( $t$ ) at different initial concentrations of Cr(VI) at 30°C is shown in Figure 9(a). It showed that about 95% adsorption of Cr(VI) was achieved during the first 10 mins of contact time, and only 5% additional adsorption occurred in the subsequent 60 mins. There was no significant influence of contact time on the adsorption efficiency after 60 mins. Therefore, the adsorption rate can be analyzed by a pseudo-second-order rate model<sup>27</sup>

$$\frac{d(q_t)}{dt} = k_2(q_e - q_t)^2 \quad (4)$$



**Figure 7** Adsorption isotherm curve of Cr(VI) with cellulosic ion exchange fiber.



**Figure 8** Linear regression analysis of (a) Langmuir equation and (b) Freundlich equation.

where  $q_t$  and  $q_e$  are the amounts of Cr(VI) adsorbed ( $\text{mg g}^{-1}$ ) onto the adsorbent at time  $t$  and at equilibrium, respectively, and  $k_2$  is the pseudo-second-order rate constant [ $\text{g (mg min)}^{-1}$ ]. Integrating Equation 4 with the conditions  $q_t = 0$  at  $t = 0$  and  $q_t = q_t$  at  $t = t$  and rearranging gives

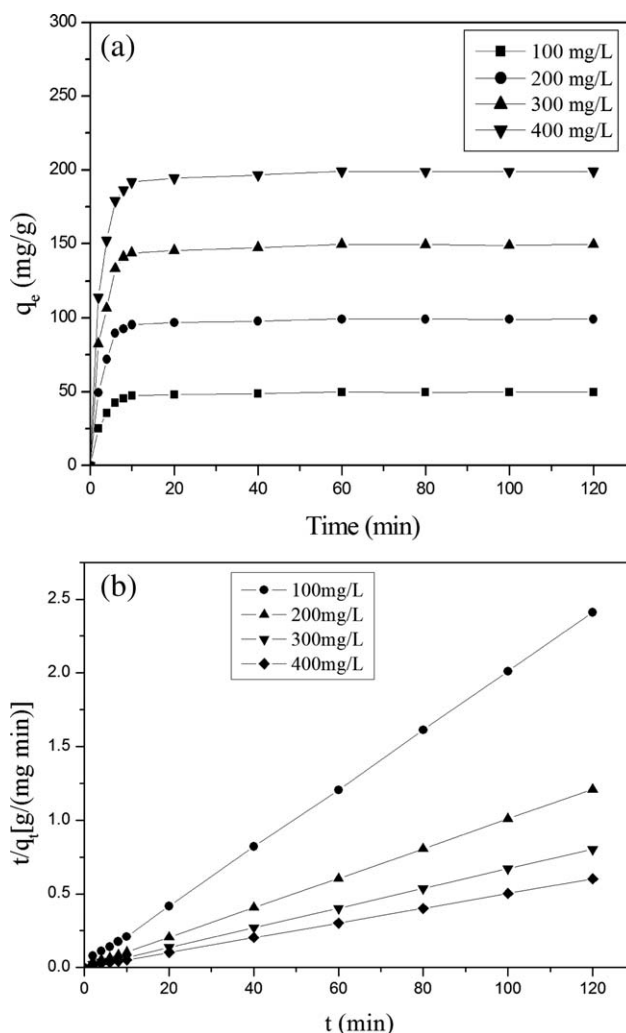
$$\frac{1}{q_e - q_t} - \frac{1}{q_e} = k_2 t \tag{5}$$

or equivalently,

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{6}$$

The values of  $k_2$  and  $q_e$  were determined using linear regression analysis with the statistical software ORIGIN version 7.5 for windows. The correlation coefficients ( $R^2$ ) values of the pseudo-second-order equation for linear plots were  $R^2 > 0.999$ , respectively, for the selected concentration range (100–400

$\text{mg L}^{-1}$ ), which suggests that the adsorption kinetics can be well described by the pseudo-second-order equation. The slope and intercept of  $\left(\frac{t}{q_t}\right)$  versus  $t$  were used to calculate the rate constant  $k_2$  and  $q_e$ . From Figure 9(b), it was observed that the theoretical values of  $q_t$  for the all concentrations were very close to the experimental  $q_t$  values. The values of  $q_e$  from the slope of plot were found to be 49.8, 99.3, 149.6, and 195.7  $\text{mg g}^{-1}$  for initial concentrations of 100, 200, 300, and 400  $\text{mg L}^{-1}$ , respectively. The values of  $k_2$  calculated according to the intercept were found to be  $1.99 \times 10^{-2}$ ,  $1.18 \times 10^{-2}$ ,  $0.83 \times 10^{-2}$ , and  $0.69 \times 10^{-2} \text{ g (mg min)}^{-1}$  for initial concentrations of 100, 200, 300, and 400  $\text{mg L}^{-1}$ , respectively. This suggests that the adsorption of Cr(VI) onto CIEF follows a pseudo-second-order kinetic model. The adsorption capacity was found to be highly dependent on the initial concentration of Cr(VI) in solution. An increase in adsorption capacity corresponding to an increase in initial adsorbate



**Figure 9** (a) Adsorption curves of Cr(VI) with CIEF at different initial concentrations of Cr(VI). (b) Linear regression analysis of pseudo-second-order equations.

**TABLE I**  
The Efficiency of Adsorption/Desorption for Four Cycles

Cycle number	Adsorption (%)	Desorption (%)
1	99.5	98.7
2	98.9	97.8
3	97.2	95.3
4	95.1	90.5

concentration. Thus, this method is suitable for the removal of relatively high concentrations of Cr(VI) present in wastewater.

### Desorption experiments

Desorption experiments from spent CIEF were studied. The desorbing agent used was 1M HCl. The amount of Cr(VI) desorbed in 2 h was measured. The adsorption/desorption data are presented in Table I. The efficiency of 98.7% desorption of Cr(VI) was obtained in the first cycle, and this value decreased to 90.5% at the end of the fourth cycle. The adsorption of Cr(VI) onto CIEF decreased from 99.5% in the first cycle to 95.1% in the fourth cycle. These results indicate that spent CIEF can be regenerated and reused after treatment with 1M HCl solution.

### CONCLUSIONS

A cellulosic anion exchange fiber was prepared by using room-temperature ionic liquid 1-(3-chloro-2-hydroxypropyl)-3-methylimidazolium chloride as reaction reagent and medium. The effects of the reaction temperature and time on DS were studied. The results showed that the degree of the CIEF substitution is up to 0.78. The product was characterized by FTIR spectrometry, thermogravimetric analysis, and SEM. The thermal stability of the CIEF is over 200°C.

The CIEF has been demonstrated to be a very efficient adsorption for the removal of Cr(VI) from aqueous solutions. The adsorption was found to be dependent on the solution pH, with the maximum removal was observed at pH < 6.0. The adsorption process achieved more than 99.6% Cr(VI) removal from an initial concentration of 50 mg L<sup>-1</sup>. The equilibrium time was found to be 1 h for the adsorption process. The experimental data for the equilibrium adsorption of Cr(VI) onto CIEF were fitted to the Langmuir isotherms, and the adsorption kinetics can be well described by the pseudo-second-order equa-

tion. The maximum adsorption capacity of CIEF for Cr(VI) was 196.1 mg g<sup>-1</sup> at 30°C. The study of adsorption/desorption confirmed that the spent adsorbent can be regenerated easily by hydrochloric acid and reused for multiple cycles of treatment without any considerable reduction of its adsorption capacity.

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