

# Adsorption of Cu(II) from Aqueous Solutions by Ammoniated Cotton Fiber

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## ABSTRACT

This study describes the preparation of a novel chelating cotton fiber adsorbent, ammoniated cotton fiber (ACF), which was prepared by modifying cotton fiber with amino-HBP using glutaraldehyde as a cross-linking agent. This new adsorbent was characterized and analyzed for amine content, and by scanning electron microscopy, Fourier transform infrared spectroscopy and X-ray photoelectron spectroscopy. The capacity of ACF to adsorb Cu(II) from aqueous solution was evaluated at different pHs, contact times and initial metal ion concentrations. The results showed that ACF was effective in removing of Cu(II) from aqueous solutions and the adsorption amount of Cu(II) reached 16.7374 mg g<sup>-1</sup>. The adsorption isotherm and kinetics were well fitted to the Langmuir model and the pseudo-second-order model, respectively. The adsorption amount calculated using the pseudo-second-order model was in good agreement with the experimental data.

**Keywords:** Cotton fiber; Hyperbranched polymer; Adsorbent; Adsorption; Heavy metal ion

## INTRODUCTION

Industrial activities and technology development can lead to serious environmental pollution due to waste streams of heavy metals being poured into rivers from many industries. This occurs in many industries, including mining, smelting, metal plating, pigment, battery manufacturing processes, metallurgical industries, etc. [1-3]. Copper is a widely used heavy metal and the cupric ion, Cu(II), is the most common species found in the environment. Copper in this form is toxic to many living organisms [3-5]. While copper in trace amounts is essential to living organisms, excessive copper in water may cause any harmful effects, including neurotoxicity, jaundice,

diarrhea, respiratory difficulties, liver and kidney failure, and death [5-7]. Thus, the removal of excess Cu(II) from wastewater needs urgent attention.

Known methods for separation and removal of Cu(II) from wastewater include adsorption using activated carbon, modified silicates, chelating polymeric resins, biopolymers and biomass [8-10]. Recently many studies have focused on preparation and application of fibrous chelating materials derived from natural biomass [11-13].

Chelating biomass fiber has many advantages compared to conventional chelating materials in form of beads or membranes. First, the material is easily prepared, extracted and modified. Secondly, chelating groups with strong affinities toward certain metal ions are readily available. Lastly the fibers can be formed into as felts or fabrics with high surface areas, which enhance the rate of reaction and regeneration [9,11,14].

Many studies have focused on the evaluation of modified cellulosic materials as efficient and inexpensive biosorbents for removal of metal ions from wastewater [8,15-18]. Shukla and Pai [17] prepared dye loaded jute and oxidized jute as adsorbents for removing Cu(II), Ni(II) and Zn(II) from aqueous solutions. The study showed that the adsorption capacity of the dye loaded jute fibers reached 8.4, 5.26 and 5.95 mg/g for Cu(II), Ni(II) and Zn(II), respectively. The corresponding values for oxidised jute fibers were 7.73, 5.57 and 8.02 mg/g, as against 4.23, 3.37 and 3.55 mg/g for unmodified jute fibers. El-Khouly et al.[18] prepared a type of amidoximated grafted cellulose designated as C-g-PAN. The adsorption capacity of C-g-PAN was

1.7 mmol/g, 1.6 mmol/g and 0.84 mmol/g for Co(II), Cu(II), Ni(II), respectively at the highest original metal ion concentration. Monier et al. [8] prepared chelating cotton fibers, known as C-PTS. Adsorption studies showed that the percent removal of Au(III), Pd(II) and Ag(I) was 98.4%, 76.3% and 62.5%, respectively. In recent years, hyperbranched polymers have received much attention and development due to their unique chemical and physical properties, one-step synthesis, a large number of functional end-groups and efficient large scale production [19]. However, there were few studies focused on the modification of cellulose using hyperbranched polymers as modifiers.

In this article, a novel ammoniated cotton fiber (ACF) as a type of chelating fiber adsorbent was prepared. ACF is based on cellulosic cotton fiber modified by amino-terminated hyperbranched polymer (amino-HBP) using glutaraldehyde as a cross-linking agent. The resulting ACF was characterized for amino content and by SEM, FT-IR and XPS. Various parameters such as pH, temperature, adsorption isotherms and kinetics were also investigated in order to evaluate the optimum adsorption conditions and maximum adsorption capacity.

## EXPERIMENTAL

### Materials

The cotton fibers used in this work were obtained from Suzhou Yintong Cotton Industry Co., Ltd (Suzhou, China). Sodium hydroxide, sodium periodate, methyl acrylate, tetraethylenepentamine, methanol, glutaraldehyde (25 wt.% solution), salicylaldehyde, pyridine, sodium methoxide, phenolphthalein, copper(II) nitrate hydrate were all analytical grade and were purchased from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China).

### Preparation of OCF

Cotton fiber (CF) was preprocessed using sodium hydroxide according to previous studies [20,21] in order to decrease the crystallinity. The preprocessed cotton fiber was then oxidized with sodium periodate solution (2 wt.%), with a bath ratio of 1:50, at 70°C, for 2 hours, washed with deionized water several times to remove the oxidant, and dried in vacuum oven.

### Preparation of amino-HBP

Amino-terminated hyperbranched polymer (amino-HBP) was synthesized according to the method described by Zhang et al., [22] by reacting

tetraethylenepentamine (0.5mol) with methyl acrylate (0.5mol). The structure of amino-HBP is shown in Figure 1.

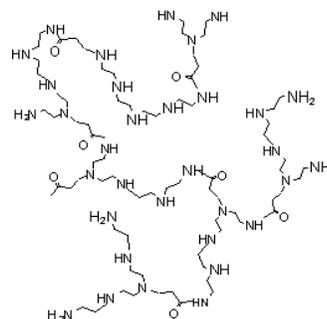


FIGURE 1. Structure of amino-HBP.

### Preparation of ACF

Approximately 1.0 g of OCF was placed in a three-necked flask which contained 30 mL of distilled water. In order to fully saturate the fibers, the mixture was stirred while raising the temperature to 70°C. After diluting with 20 mL of distilled water, 2.5 g of glutaraldehyde (25 wt. % solution) was slowly added to the mixture with the temperature at 70°C for 30 min. Then, 10 mL of amino-HBP solution (10 wt. %) was slowly added to the mixture over 4 hours at 70°C to yield the dark brown ammoniated cotton fiber (ACF). The ACF was filtered through a nylon cloth and repeatedly washed with distilled water to remove the unreacted glutaraldehyde and amino-HBP. The preparation route used to obtain ACF is shown in Figure 2 and pictures of CF, OCF and ACF are shown in Figure 3.

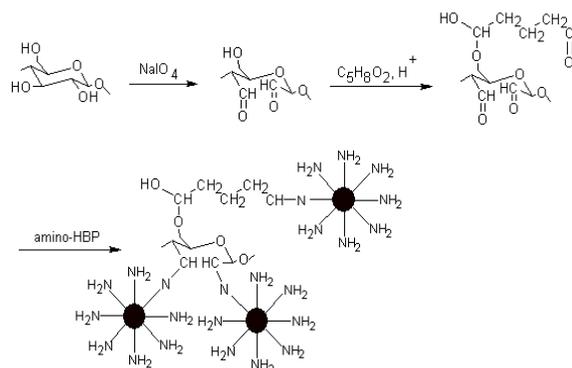


FIGURE 2. Preparation route used to obtain ACF.



FIGURE 3. Pictures of CF, OCF and ACF.

## **Characterization of ACF**

### ***Amino Content***

Amine content of the adsorbent was determined by the salicylaldehyde method [23]. Ten mL of salicylaldehyde pyridine standard solution (0.5 M) was added to a 250 mL iodine flask containing 0.1 g adsorbent. After 4 hours at room temperature, 1 mL phenolphthalein pyridine standard solution (1 wt.%) was added. This solution was titrated with sodium methoxide pyridine standard solution (0.4233 M) until dark blue and the volume of sodium methoxide solution used was recorded. A blank experiment was conducted simultaneously. The amino content (wt.%) of the adsorbent was calculated by using Eq. (1):

$$-NH_2(\%) = \frac{(V_0 - V_1) \times N \times M}{1000 \times W} \times 100\% \quad (1)$$

Where  $V_0$  is the volume of sodium methoxide pyridine standard solution (0.4233 M) consumed by 10 mL salicylaldehyde pyridine standard solution (0.5 M);  $V_1$  is the volume of sodium methoxide pyridine standard solution (0.4233 M) consumed by 10 mL salicylaldehyde pyridine standard solution (0.5 M) reacted with 0.1 g adsorbent;  $N$  is the concentration of sodium methoxide pyridine standard solution (0.4233 M);  $M$  is the molecular weight of primary amine ( $\text{g mol}^{-1}$ ) and  $W$  is the mass of the adsorbent (g).

### ***SEM Analysis***

The surface morphology of CF, OCF and ACF was observed using an S-4800 scanning electron microscope (SEM) (Hitachi, Japan). Prior to examination, the samples were gold sputter-coated under an argon atmosphere to render them electrically conductive. Images were then recorded at an excitation voltage of 3 kV.

### ***FT-IR Analysis***

The CF, OCF and ACF were cut into micron-size powder and samples were prepared by mixing 1 mg of material with 100 mg of spectroscopy grade KBr. The FTIR spectra were recorded using a Nicolet 5700 FTIR spectrometer (Thermo Nicolet, USA) with a detector at  $4 \text{ cm}^{-1}$  resolution. Spectra were taken from 500 to  $4000 \text{ cm}^{-1}$  at 32 scans per sample.

### ***XPS Analysis***

X-ray photoelectron spectroscopy (XPS) was conducted via the Axis Ultra HAS system (Shimadzu, Japan). The CF and ACF were cut into micron-size powder and compressed into thin slices for detection.

### ***ICP-OES Analysis***

Heavy metal concentration of the initial and adsorbed solutions was measured by a Vista MPX inductively coupled plasma atomic emission spectrometer (ICP-OES) (Spectro Analytical Instruments GmbH, Germany).

## **Methods**

### ***Effect of pH on Adsorption***

To study the effect of pH on adsorption, 0.1 g of adsorbent ACF was added into 50 mL of copper nitrate trihydrate solution containing  $100 \text{ mg L}^{-1}$  Cu(II). The initial pH values of the solutions were adjusted to 2.01, 2.50, 3.00, 3.52, 3.99, 4.49, 5.00, 5.52, 5.97, 6.23, and 6.51 using either 0.1 M NaOH or 0.1 M HCl. The adsorption experiments were conducted at  $30^\circ\text{C}$  for 4 h under agitation in a water-bath. After adsorption, the Cu(II) concentration of the solution was determined using an inductively coupled plasma atomic emission spectrometer (ICP-OES). Finally, the effect of pH on adsorption was analyzed using the adsorption capacity as the reference index [24,25].

### ***Contrast Experiments***

About 0.1 g of CF, OCF and ACF were individually added into 50 mL of copper nitrate trihydrate solution containing  $100 \text{ mg L}^{-1}$  Cu(II). The pH values of the solutions were adjusted to 5.0 by using 0.1 M HCl and 0.1 M NaOH. The adsorption experiments were conducted at  $30^\circ\text{C}$  for 4 h under agitation. After adsorption, the Cu(II) concentration of the solution was determined using the ICP-OES. Finally, the adsorption capacities of CF, OCF and ACF on Cu(II) were determined.

### Adsorption Isotherms

Cu(II) stock solution containing  $100 \text{ mg L}^{-1}$  Cu(II) was prepared by dissolving copper nitrate trihydrate with distilled water to achieve the desired concentration. About 0.1 g ACF was added to 50 mL of copper nitrate trihydrate solutions containing about 10, 20, 30, 40, 50, 60, 70, 80, 90, and  $100 \text{ mg L}^{-1}$  Cu(II), respectively. The initial pH of each solution was adjusted to 5.0 by using 0.1 M HCl and 0.1 M NaOH. The adsorption experiments were conducted under agitation for 4 h at 30, 35 and  $40^\circ\text{C}$ , and the adsorption isotherm curves were obtained according to the method of Qiang [25].

### Adsorption Kinetics

A total of 1.0 g of ACF was added to 500 mL of  $100 \text{ mg L}^{-1}$  Cu(II) solution. The initial pH of the solution was adjusted to 5.0 by using 0.1 M HCl and 0.1 M NaOH. The adsorption experiments were performed at 30, 35 and  $40^\circ\text{C}$  under agitation. The Cu(II) concentration during the adsorption process was analyzed over time and the adsorption dynamics curves of different temperatures were obtained.

## RESULTS AND DISCUSSION

### Characterization of ACF

There are no amino groups on the macromolecules of CF and OCF according to their chemical structure in *Figure 2*. According to the salicylaldehyde method, the amino content of ACF was 0.3047 percent. The result indicated that the amino groups were successfully introduced into ACF after modification with amino-HBP.

The SEM images of CF, OCF and ACF are shown in *Figure 4*. There are natural convolutions on the CF. Following oxidization, the convolutions disappeared and many cracks were appeared on the surface of OCF due to oxidation and hydrolysis of the cellulose macromolecule chains. A layer of amino-HBP film was formed on the surface of ACF after modification, filling the cracks.

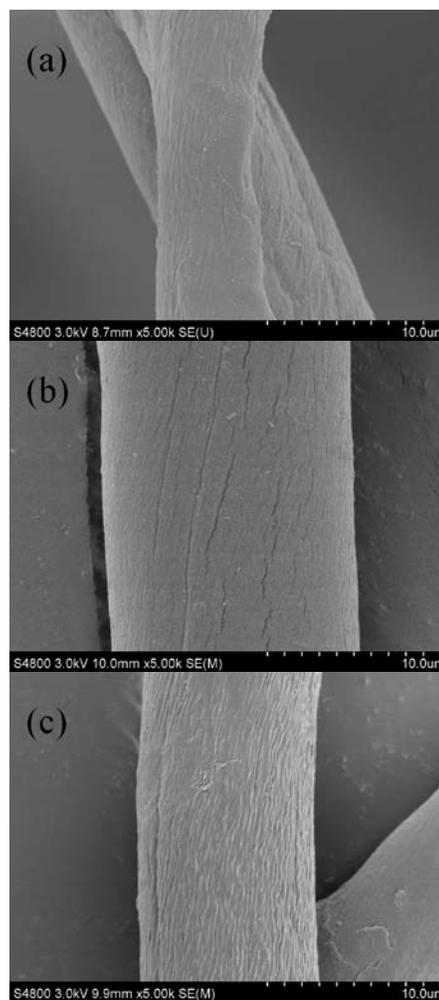


FIGURE 4. SEM images of fibers. (a) CF, (b) OCF, (c) ACF

In order to verify that the amino-HBP was successfully grafted to the ACF, the fibers were characterized using FTIR spectroscopy. *Figure 5* shows the infrared spectra of the CF, OCF and ACF. In the infrared spectrum of OCF, the absorbance band at  $1729.835 \text{ cm}^{-1}$  can be assigned to the stretching vibration of the  $\sigma_{\text{C=O}}$  bond of an aldehyde group, which indicates the hydroxyl groups on the cellulose were oxidized into aldehyde groups [22]. The absorbance bands at  $1617.984 \text{ cm}^{-1}$  and  $3415.314 \text{ cm}^{-1}$  of ACF correspond to  $\delta_{\text{N-H}}$  and  $\gamma_{\text{N-H}}$  of the primary amine of the amino-HBP [26,27], which indicate amino-HBP was grafted to ACF, and the adsorbent modified by amino-HBP was successfully obtained.

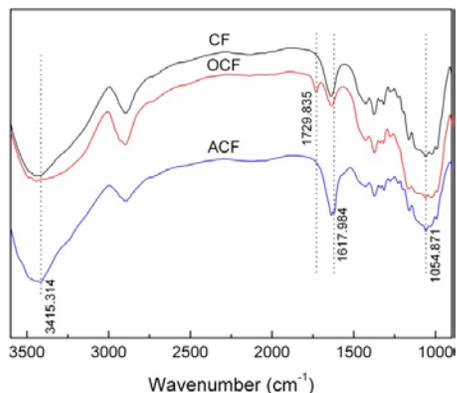


FIGURE 5. FT-IR spectra of CF, OCF and ACF.

XPS was performed to investigate the main component elements of CF and ACF. The wide scan XPS spectrum (Figure 6) shows photoelectron lines at binding energies of about 285 and 530 eV, which are attributed to C1s and O1s, respectively. An N1s response appears at 396 eV in the spectrum of AC; this is not present in the CF spectrum. The appearance of the N1s response further proves amino-HBP was grafted to ACF.

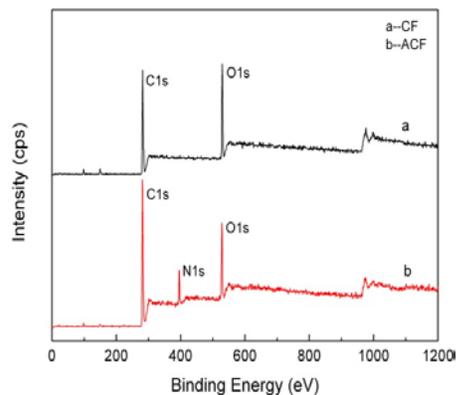


FIGURE 6. XPS spectra of CF and ACF.

### Effect of pH

Solution pH is one of the crucial parameters affecting the adsorption of metal ions from aqueous solution; it can influence the solubility of the metal ions, concentration of the counter ions on the adsorbent and the degree of ionization of the adsorbate during reaction [28]. Chemical reactions of heavy metals in solution, including hydrolysis, complexation by ligands, redox reactions, and precipitation also can be influenced by pH [29]. The dependence of metal ion removal on pH is related to both surface functional groups present on the adsorbent and the form of the metal ions in solution [10,30].

To study the effect of pH on Cu(II) sorption by ACF, the solution initial pH was varied within the range of 2.01–6.51. This pH range was chosen to avoid copper hydroxide precipitation. ACF is a weakly basic adsorbent that contains basic functional groups as Figure 2 shows. At low pH, amino functional groups of ACF closely associate with hydronium ions ( $H_3O^+$ ) and restrict the approach of metal cations as a result of the repulsive force. The effect of pH on Cu(II) adsorption is shown in Figure 7.

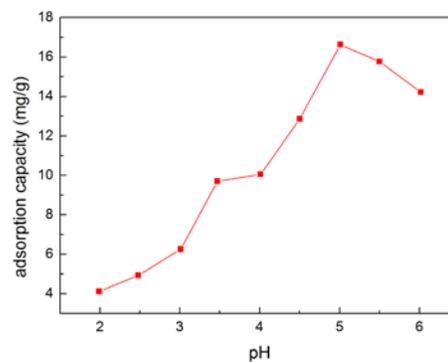


FIGURE 7. Effect of pH on adsorption.

The adsorption capacity of Cu(II) increased with pH until pH reached 5.00, and then it decreased as the pH increased to 6.00. At lower pH values, the higher concentration of hydrogen ions effectively led to fewer ligands being available for metal ion binding [10,30]. The dependence of metal ion uptake on pH suggests that the weak basic amine groups of ACF might be protonated or partially protonated. Thus, it is expected that at lower pH values the binding sites were occupied by protons and that hydronium and metal ions compete for the free binding sites [30]. As pH increases, the adsorbent surface became deprotonated, resulting in more ligand groups available for metal ion binding, and free electron-pairs from amine groups were likely enhanced. Therefore, more amine functional groups take part in metal ion uptake by complexation reaction or chelating and the adsorbed amount consequently increases. As can be seen from Figure 7, the optimum pH for the adsorption of Cu(II) was 5.0. All subsequent experiments were conducted at this pH level.

### Contrast Experiments

The adsorption capacities of Cu(II) on CF, OCF and ACF are shown in Figure 8. The results showed that the adsorption capacity of Cu(II) from the copper solution increased significantly after being modified by amino-HBP. When about 0.1 g adsorbent was

added into 50 mL of copper nitrate trihydrate solution containing  $86.43 \text{ mg L}^{-1} \text{ Cu(II)}$ , the adsorption ability of ACF of  $\text{Cu(II)}$  was  $16.7374 \text{ mg g}^{-1}$  while that of CF was only  $1.6169 \text{ mg g}^{-1}$  and that of OCF was  $3.1621 \text{ mg g}^{-1}$ . These results indicated that the amino content of ACF increased significantly after being modified by amino-HBP, and the adsorption capacity of is  $\text{Cu(II)}$  enhanced.

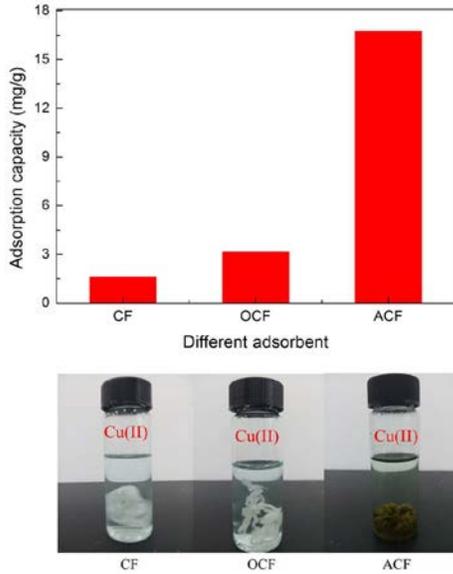


FIGURE 8. Adsorption capacity of CF and ACF on  $\text{Cu(II)}$ .

### Adsorption Isotherms

The adsorption isotherms of  $\text{Cu(II)}$  on ACF at different temperatures are shown in Figure 9. The adsorption capacity was  $17.3255 \text{ mg g}^{-1}$  at  $40^\circ\text{C}$  when the initial concentration of  $\text{Cu(II)}$  in solution was  $87.26 \text{ mg L}^{-1}$ . The adsorption isotherms of  $\text{Cu(II)}$  on ACF indicated that the adsorption capacity increased slightly as the temperature and the equilibrium concentration of  $\text{Cu(II)}$  increased, which suggests that the adsorption of  $\text{Cu(II)}$  on ACF was mainly chemical. Figure 9 also shows that adsorption at room temperature is nearly the same as that at  $40^\circ\text{C}$ . Removal rates of  $\text{Cu(II)}$  at different temperatures are shown in Figure 10. Removal rates of  $\text{Cu(II)}$  decreased with the increasing initial concentration. The removal rate was 91.3 wt.% at  $40^\circ\text{C}$  when the initial concentration of  $\text{Cu(II)}$  in solution was  $7.909 \text{ mg L}^{-1}$ .

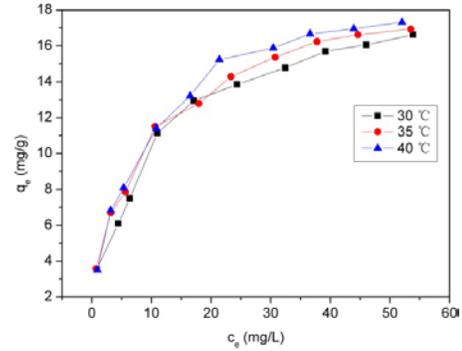


FIGURE 9. Adsorption isotherms of ACF at different temperatures.

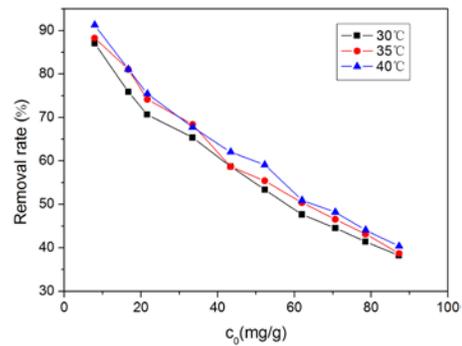


FIGURE 10. Relationship between initial concentration of  $\text{Cu(II)}$  and removal rate.

The adsorption data were analyzed using linear forms of the Langmuir and Freundlich isotherm models. The Langmuir isotherm applies to adsorption on completely homogeneous surfaces with negligible interaction between adsorbed molecules. It is represented as Eq. (2) [31].

$$\frac{c_e}{q_e} = \frac{c_e}{q_m} + \frac{1}{K_L q_m} \quad (2)$$

where  $q_e$  is the equilibrium adsorption capacity of ions on the adsorbent ( $\text{mg g}^{-1}$ ),  $c_e$  is the equilibrium ion concentration in solution ( $\text{mg L}^{-1}$ ),  $q_m$  is the maximum capacity of the adsorbent ( $\text{mg g}^{-1}$ ),  $K_L$  is the Langmuir adsorption constant ( $\text{L mg}^{-1}$ ) relating to the adsorption strength.

The Freundlich isotherm is applicable to heterogeneous surfaces and multilayer sorption. It is expressed as Eq. (3) [31].

$$\ln q_e = \frac{1}{n} \ln c_e + \ln K_F \quad (3)$$

where equilibrium capacity  $q_e$  and  $c_e$  are defined as above, while  $K_F$  and  $1/n$  are the Freundlich constants representing adsorption capacity and adsorption intensity, respectively.

Table I shows the Langmuir and Freundlich parameters for adsorption of Cu(II) on ACF. The linear Langmuir isotherm plots and Freundlich isotherm plots for the sorption of Cu(II) onto ACF are shown in Figure 11. Based on the  $R^2$  values, the linear form of the Langmuir isotherm appears to produce a reasonable model for adsorption. The

fitting results of the Langmuir equation showed a certain degree of correlation and suggested that physical adsorption might be involved in the Cu(II) adsorption on ACF. The value of  $1/n$  is lower than 1, indicating the surface of the adsorbent was heterogeneous and adsorption occurred easily [25,32]. The maximum adsorption capacities ( $q_m$ ) calculated by the Langmuir isotherm at 30, 35 and 40°C are shown in Table I. The maximum adsorption capacities for Cu(II) are 18.73361, 18.67065 and 19.33488  $\text{mg g}^{-1}$ , respectively.

TABLE I. Langmuir and Freundlich parameters for adsorption of Cu(II) on ACF at different temperatures.

Temperature	Langmuir equation			Freundlich equation		
	$K_L$ ( $\text{L mg}^{-1}$ )	$q_m$ ( $\text{mg g}^{-1}$ )	$R^2$	$1/n$	$K_F$	$R^2$
30 °C	0.12711	18.73361	0.99376	0.38948	3.77602	0.98211
35 °C	0.16296	18.67065	0.99259	0.36515	4.33174	0.98543
40 °C	0.15921	19.33488	0.99620	0.37527	4.34015	0.98552

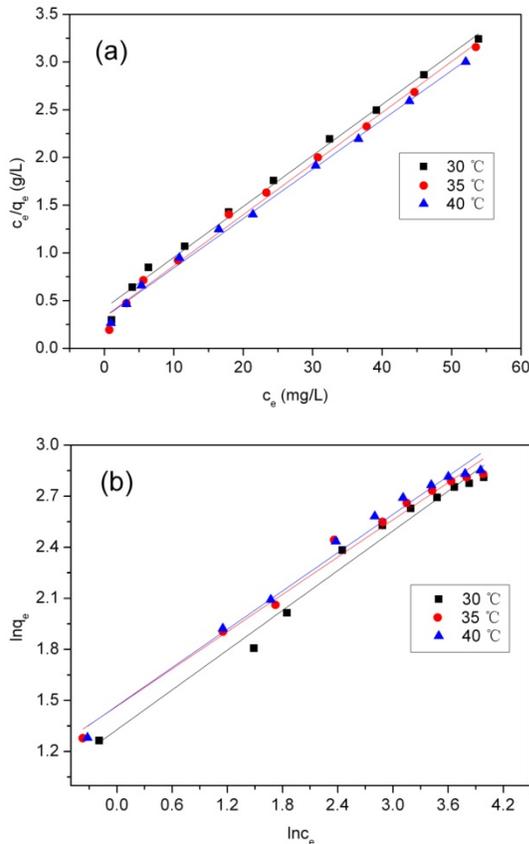


FIGURE 11. Adsorption isotherm model of ACF at different temperatures. (a) Langmuir model, (b) Freundlich model.

### Adsorption Kinetics

The adsorption kinetics of Cu(II) on ACF was investigated by two kinds of kinetics models: Lagergren pseudo-first-order and pseudo-second-order models, as in Eq. (4) and Eq. (5), respectively. The pseudo-first-order and pseudo-second-order equations were used to test the adsorption kinetic data and investigate the adsorption mechanism [31].

Pseudo-first-order model is expressed in the form of:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (4)$$

Pseudo-second-order model is represented as:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (5)$$

where  $q_e$  ( $\text{mg g}^{-1}$ ) is the adsorption capacity at adsorption equilibrium,  $q_t$  ( $\text{mg g}^{-1}$ ) is the adsorption at time  $t$  (min),  $k_1$  ( $\text{min}^{-1}$ ) is the rate constant of the pseudo-first-order adsorption, and  $k_2$  ( $\text{mg g}^{-1} \text{min}^{-1}$ ) is the constant of the pseudo-second-order rate.

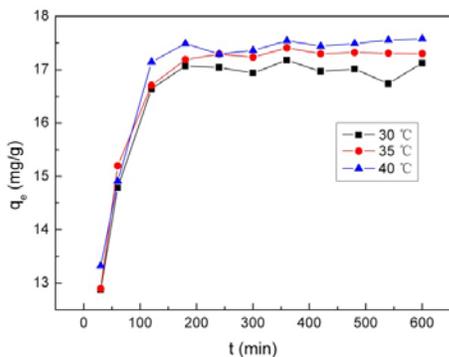


FIGURE 12. Adsorption kinetics of ACF at different temperatures.

The adsorption kinetics of Cu(II) on ACF at different temperatures is shown in Figure 12. The experimental data indicates that the Cu(II) adsorption rates on ACF were initially fast and then slowed down as equilibrium was approached. The

adsorption equilibrium was attained after 3 h and the maximum adsorption capacity was 17.5799 mg g<sup>-1</sup> accordingly at 40°C when the initial concentration of Cu(II) in solution was 98.88 mg L<sup>-1</sup>.

The kinetic adsorption data were fitted to Eq. (4) and (5). The calculated results are listed in Table II and pseudo-first-order and pseudo-second-order plots are given in Figure 13. The correlation coefficients ( $R^2$ ) for the pseudo-second-order kinetics model were in the range of 0.99944~0.99983 at different temperatures, whereas the pseudo-first-order adsorption correlation coefficients ( $R^2$ ) were in the range of 0.34017~0.63945. These results suggest the equilibrium adsorption capacities calculated by the pseudo-second-order model were in good agreement with the experimental data. Thus, the pseudo-second-order equation better describes the adsorption behavior of Cu(II) on ACF.

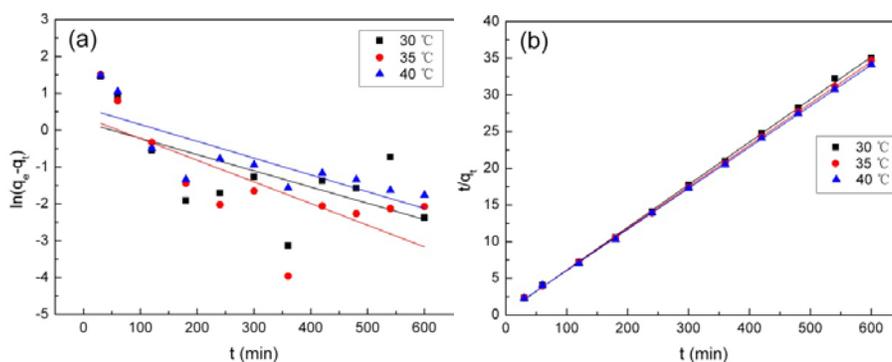


FIGURE 13. Adsorption kinetics model of ACF at different temperatures. (a) Pseudo-first-order model, (b) Pseudo-second-order model.

TABLE II. Kinetics parameters for adsorption of Cu(II) on ACF at different temperatures.

Temperature	Pseudo-first-order equation			Pseudo-second-order equation		
	$q_e$ (mg g <sup>-1</sup> )	$k_1$ (min <sup>-1</sup> )	$R^2$	$q_e$ (mg g <sup>-1</sup> )	$k_2$ (g mg <sup>-1</sup> min <sup>-1</sup> )	$R^2$
30 °C	1.24645	0.00441	0.34017	17.21170	0.01009	0.99944
35 °C	1.43366	0.00589	0.50532	17.58087	0.00820	0.99982
40 °C	1.83648	0.00456	0.63945	17.81896	0.00723	0.99983

## CONCLUSION

ACF was successfully prepared by modifying cotton fiber with amino-HBP using glutaraldehyde as a cross-linking agent. After modification, the amino content increased to 0.3047% from 0%. ACF is an effective adsorbent for removal of Cu(II) from aqueous solutions with the adsorption capacity of

Cu(II) reaching 16.7374 mg g<sup>-1</sup> after modification while that of CF was only 1.6169 mg g<sup>-1</sup>. Adsorption studies demonstrated that a solution pH of 5.00 results in maximum adsorption of Cu(II) onto ACF. Equilibrium adsorption data were best fitted by the Langmuir model. Maximum adsorption amounts for

removal of Cu(II) were found to be 18.73361 mg g<sup>-1</sup>, 18.67065 mg g<sup>-1</sup> and 19.33488 mg g<sup>-1</sup> at 30, 35 and 40°C, respectively. The pseudo-second-order model provided a better description of the adsorption behavior of Cu(II) on ACF. Adsorption studies showed that ACF had strong adsorption capacity of Cu(II), which suggests that the ACF resulting from this work could be a good candidate for the treatment of wastewater containing Cu(II).

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