

Preparation of Betaine-Modified Cationic Cellulose and Its Application in the Treatment of Reactive Dye Wastewater

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ABSTRACT: Betaine-modified cationic cellulose was prepared through the reaction of cellulose with betaine hydrochloride by an efficient one-step dry method. Dicyandiamide was used as a dehydrating agent to promote the formation of ester bonds between the reactants. Fourier transform infrared spectroscopy, X-ray diffraction, and scanning electron microscopy were used to characterize the cellulose betainate. Experiments showed that at a molar ratio of the cellulose glucose unit, betaine hydrochloride to dicyandiamide, of 1:1:0.5 at 150°C for 3 h, the degree of substitution of the cationic group reached 0.80. The adsorption of simulated C. I. Reactive Red 24 and C. I. Reactive Red 195 wastewater on the cationic cellulose was carried out, and the effects of the adsorbent dose, initial dye concentration, and salt concentration on the dye removal efficiency were investigated. The equilibrium adsorption isotherm data of the cationic cellulose exhibited a better fit to the Langmuir isotherm model than the Freundlich one. The experimental results suggest that the prepared cationic cellulose materials show potential application for reactive dye wastewater treatment. © 2014 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2014**, *131*, 40522.

KEYWORDS: adsorption; biocompatibility; cellulose and other wood products; dyes/pigments

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INTRODUCTION

With the rapid development of the dyeing industry, water pollution arising from dyeing wastewater has become a serious environmental problem. The wastewater damages not only the aesthetic nature of the environment but also the entire aquatic ecosystem, so the removal of color from wastewater becomes environmentally important. Among commercially applied dyes, reactive dyes account for a large share. However, the utilization ratio of the dyes is only 50–70%, and a tremendous amount of dyeing effluent is discharged.¹ The treatment of reactive dye wastewater is quite essential, and the concerning studies have been extensive.^{2,3}

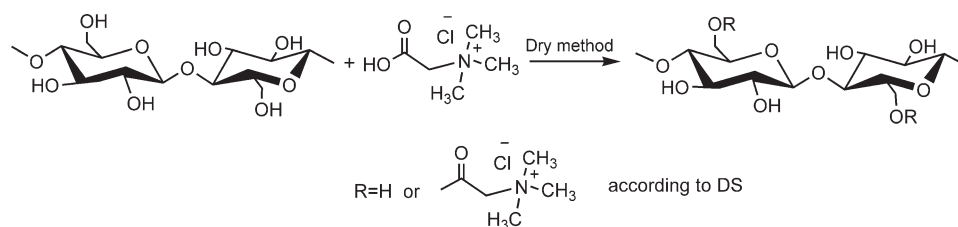
The use of an adsorbent to treat dye wastewater is a widely employed method because of its advantages of simple operation and good treatment effects.^{4–8} In recent years, the safety of adsorbents themselves has received great attention with increasing awareness of environmental protection. Biomass-based adsorbents, such as cellulose-, starch- and chitin-based adsorbents have been widely researched.^{9–12} As a type of reproducible resource, cellulose is rich in nature and shows biodegradable, nontoxic, and inexpensive features. It also has the characteristics

of being a natural polymer, is not water-soluble, and has a long chain with a large amount of reactive hydroxyl groups, which can be used to introduce more functional groups for dye adsorption. Cationic cellulose obtained by the introduction of cationic groups to cellulose can be used to adsorb anionic dyes; this is mainly because of the electrostatic attraction between the modified cellulose and the dyes. The preparation of cationic cellulose, which could be used for treatment of reactive dyes, has also been studied.^{13–15} Conventional cationic agents used to modify cellulose are usually synthetic compounds; their use still shows an underlying hazard to the environment.¹⁶ Therefore, the synthesis of an environmentally friendly cellulose-based cationic adsorbent is of great importance.

In this study, betaine hydrochloride was used as a cationic agent to modify cellulose for the preparation of a novel cationic adsorbent. Betaine (*N,N,N*-trimethyl glycine) is a kind of quaternary ammonium base and an abundant natural product. Betaine hydrochloride can be easily obtained from betaine through acidification, and it is commonly used as a feed additive. Betaine hydrochloride contains not only cationic quaternary ammonium salt but also carboxyl groups. In this study, the carboxyl group of betaine hydrochloride was used to react

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Scheme 1. Synthesis of cellulose betainate.

with the hydroxyl groups of cellulose to prepare cationic cellulose–cellulose betainate. The application of the obtained cellulose derivative as an adsorbent will be of significance in the consideration of environmental concerns. Until now, there has been no report on the synthesis and application of cellulose betainate.

Previous studies on the synthesis of cellulose esters^{17,18} or betainate^{19,20} have shown that acyl chloride or acid anhydride, which is quite unstable, is usually synthesized first, and then, it reacts with hydroxyl-containing compounds to form esters. The reaction is usually carried out in an organic solvent. A dry method, namely, a nonsolvent method, has also been reported for the synthesis of some cellulose derivatives or other polysaccharide derivatives,^{21,22} and it exhibited the advantages of being more environmentally friendly and convenient compared with the solvent method. The dry method was adopted to synthesize the new cationic cellulose–cellulose betainate. In this study, to promote dehydration between cellulose and betaine hydrochloride, the dehydrating agent dicyandiamide was used. Dicyandiamide is nontoxic and has been reported as a dehydrating agent for a long time. The dehydrating mechanism of the cyanamide compound was already studied.²³ It was once used in the dyeing of cotton fibers with dyes containing carboxyl groups.²⁴ A high dye fixation was achieved with the addition of dicyandiamide, and the formation of ester bonds between the fibers and the dyes was proven. We also selected dicyandiamide as a dehydrating agent because the agent is water-soluble and can be easily separated from the cellulose betainate product. Moreover, it is stable at high temperature and suitable for use in the dry method synthesis.

The objectives of this study were to synthesize cellulose betainate with a dry method (the reaction procedure is shown in Scheme 1), characterize its structure, investigate the reaction conditions and then to study adsorption performance of this new adsorbent for a simulated reactive dye wastewater: hydrolyzed C. I. Reactive Red 24 (HRR 24) and hydrolyzed C. I. Reactive Red 195 (HRR 195). The structures of both dyes are shown in the Supporting Information.

EXPERIMENTAL

Materials

Microcrystalline cellulose (MCC) used in this study was purchased from Sinopharm Chemical Reagent Co., Ltd., China. Betaine hydrochloride was purchased from Hangzhou Wanjing New Materials Co., Ltd., China. Dicyandiamide and sodium hydroxide were both analytical reagent grade reagents and purchased from Tianjin Bodi Chemical Co., Ltd., China. Two com-

mercially available reactive dyes, C. I. Reactive Red 24 (RR 24) and C. I. Reactive Red 195 (RR 195), were purchased from Shanghai Dyestuff Co., Ltd., China and were used without further purifications.

Preparation of Cellulose Betainate

A certain amount of MCC was immersed in 250 g/L of sodium hydroxide solution, stirred and soaked for 1 h, then filtered and washed with water until being neutral. It was finally dried and ready for use. Cellulose betainate was synthesized with dry method: 1.08 g of alkali-treated cellulose, 1.02 g of betaine hydrochloride and 0.3 g of dicyandiamide (the molar ratio of cellulose glucose units, betaine hydrochloride to dicyandiamide was 1:1:0.5) were grinded evenly with a mortar, then quite a little amount of water was added for mixing and the mixture was placed in a Petri dish. The reaction was carried out at 150°C for 3 h in an oven and remixing of the materials was made each 0.5 h. The crude product was washed with water several times and further Soxhlet-extracted with ethanol for 24 h. The purified product was then dried *in vacuo* to obtain 1.80 g (yield 80.0%) of the product with degree of substitution (DS) of cationic group of 0.80.

Contrast Experiment 1. The preparation procedure was almost the same with that of cellulose betainate above except that dicyandiamide was not added.

Contrast Experiment 2. The preparation procedure was almost the same with that of cellulose betainate above except that 5 mL (1.32 mol/L) hydrochloric acid instead of betaine hydrochloride was added.

Preparation of the Dye Solution

Simulated reactive dye wastewater was prepared by dissolving desired amount of dyes in water, and 1 g/L of sodium hydroxide was then added under stirring at 90°C for 1 h to hydrolyze the dyes. After cooling, hydrochloric acid was used to adjust pH of the dye solution to neutral and the obtained reactive dye wastewater was ready for use.

Adsorption Experiments

The adsorption experiments of the cationic cellulose for the hydrolyzed reactive dye solutions were conducted at room temperature using the MY 3000-6K stirring instrument (Wuhan, China). The experiments are shown as below: simulated dye wastewater (50 mL) was placed in a beaker and adjusted to neutral using 0.1 M HCl solutions. A certain amount of cellulose betainate was added to the dye solution. The mixture was first stirred rapidly at 150 rpm for 60 min and then at 50 rpm for 60 min. The solution was left to settle for a period of time. The absorbance of the supernatant solution was determined by

measuring the absorbance at the maximum absorption wavelength (λ_{\max}) of each dye using an ultraviolet–visible spectrophotometer (HP 8453). The experiments were undertaken by varying the amount of the cationic cellulose and the dye concentration. The dye removal efficiency (R ; %) and the amount of the dye adsorbed (q ; mg/g) were calculated as the following equations, respectively:

$$R(\%) = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

$$q = \frac{V(C_0 - C_e)}{m} \quad (2)$$

where C_0 and C_e are the initial and final concentrations of the dye after adsorption (mg/L), respectively; V is the volume of the experimental solution (L); and m is the weight of cellulose betainate used (g).

Characterization

The nitrogen content of the cellulose betainate was obtained by the Kjeldahl method (GB12091-89) and the DS of the cationic groups in the cellulose betainate was then calculated according to eq. (3):

$$DS = \frac{162.15 \times N\%}{14.01 - 136.6 \times N\%} \quad (3)$$

where 162.15 is the molar mass of glucose units in the fiber (g/mol), 14.01 is the atomic weight of nitrogen 14.01 (g/mol), 136.6 is the molar mass of the substituent (g/mol), and $N\%$ is the nitrogen content in the sample.

The Fourier transform infrared (FTIR) spectra of alkali-treated cellulose and cellulose betainate were obtained with an FTIR-430 Spectrophotometer. All samples were prepared as potassium bromide tablets.

The X-ray diffraction (XRD) patterns of MCC, alkali-treated cellulose and cellulose betainate were performed via an X-ray diffractometer (Rigaku D/MAX2400, Rigaku Co., Ltd., Japan) using Cu $K\alpha_1$ radiation ($\lambda = 1.5406 \text{ \AA}$ at 40 kV, 100 mA in the 2θ range of $4\text{--}60^\circ$)

The surface morphologies of MCC, alkali-treated cellulose and cellulose betainate were observed directly with scanning electron microscopy (SEM; type JSM-5600LV, JEOL Co., Japan).

RESULTS AND DISCUSSION

Characterization of Cellulose Betainate

FTIR Analysis. FTIR was used to characterize the structure of the betaine-modified cationic cellulose and comparison was made with that of the unmodified one. Figure 1 shows FTIR spectra of the cellulose before (alkali-treated cellulose) and after (cellulose betainate) cationic modification. In this study, cellulose betainate is synthesized through reaction of alkali-treated cellulose with betaine hydrochloride. The purpose of alkaline treatment is to increase amorphous cellulose content, thereby improve accessibility of chemical reagents to the cellulose molecules and increase the number of possible reaction sites.²⁵ For comparison, FTIR spectra of the cellulose betainate obtained with and without (as described in “Preparation of cellulose

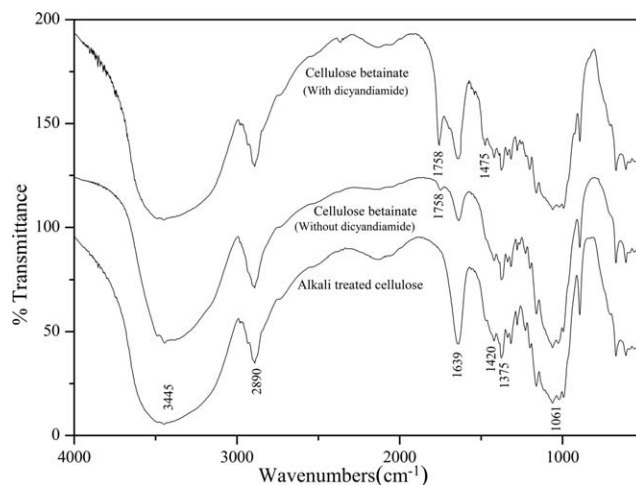


Figure 1. FTIR spectra of the alkali-treated cellulose and cellulose betainate.

betainate: Contrast experiment 1”) addition of dicyandiamide were both measured.

In Figure 1, the principal spectral features of the cellulose before cationic modification (alkali-treated cellulose) are shown as follows: 3445 cm^{-1} (absorption peak of stretching vibration of O–H), 2890 and 2974 cm^{-1} (absorption peaks of stretching vibration of C–H of CH_2 and CH), 1639 cm^{-1} (absorption peak of bending vibration of O–H), 1420 and 1375 cm^{-1} (absorption peaks of deformation vibration of C–H of CH_2 and CH), 1061 cm^{-1} (absorption peak of symmetric skeleton stretching vibration of benzene ring). Compared to the alkali-treated cellulose, betaine-modified cellulose (with addition of dicyandiamide) presents two new peaks at 1758 cm^{-1} (absorption peak of stretching vibration of C=O of the ester carbonyl group), and 1475 cm^{-1} (absorption peak of deformation vibration of C–H of CH_3 in quaternary ammonium groups), which indicated that ester bonds formed between cellulose and betaine hydrochloride (the adsorption peaks of the ester bonds of the cellulose ester and starch betainate in references both appeared at $\sim 1750 \text{ cm}^{-1}$ ^{17,19}), and quaternary ammonium groups had been introduced to cellulose. Furthermore, if the dehydrating agent dicyandiamide was not added in the preparation of cellulose betainate, IR spectrum of the product also showed formation of ester bond; however, the peak indicating ester bond (at 1758 cm^{-1}) was very small, which reveals addition of dehydrating agent can greatly promote reaction. In addition, IR spectrum of betaine hydrochloride was made (see Supporting materials), it showed the peak indicating carboxyl group appeared at 1735 cm^{-1} , which can be easily distinguished with the peak indicating the formed ester bond.

XRD Analysis. Figure 2 presents XRD patterns of MCC, alkali-treated cellulose and cellulose betainate. It can be seen the crystalline form of MCC is cellulose I. Its XRD patterns mainly exhibited three peaks at $2\theta = 14.8^\circ$, 16.2° and 22.6° . After alkali treatment, the crystalline form of the cellulose changed to be a mixture of cellulose I and cellulose II, which is the same as previously reported.^{26,27} The XRD patterns of cellulose II mainly exhibited three peaks at 12° , 19.9° , and 21.6° . Alkali swelling

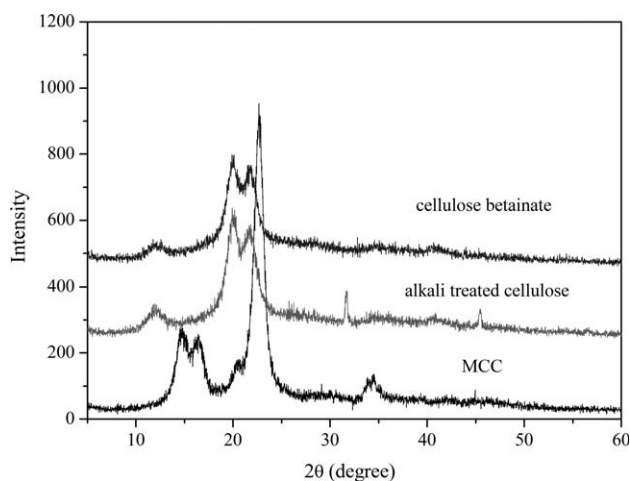


Figure 2. XRD of the MCC, alkali-treated cellulose, and cellulose betainate.

plays the role of decrystallization, resulting in the increase of the reactivity of the cellulose. Furthermore, the effect of dry method reaction conditions on the crystalline form of cellulose was studied. The results showed that the crystalline form of cellulose did not change after cationic modification compared to that of alkali-treated cellulose.

SEM Analysis. Figure 3 present SEM images of MCC [Figure 3(a,d)], alkali-treated cellulose [Figure 3(b,e)], and cellulose betainate [Figure 3(c,f)] under different magnification. When the images were magnified 1000 time, it could be seen clearly

that the cellulose swelled after alkali treatment by making comparison between Figure 3(a,b). Swelling of cellulose is beneficial for betaine hydrochloride to penetrate into the fibers to improve the reaction efficiency. Moreover, it could be seen small damages were found on some cationic cellulose [Figure 3(c)], which is mainly due to reaction under high temperature and acidic condition. When at higher magnified time of 10,000 times, surface of the alkali-treated cellulose [Figure 3(e)] seemed a little rougher due to alkali swelling compared with that of MCC [Figure 3(d)], and small damage was found on the cationic cellulose [Figure 3(f)]. This demonstrated that reaction conditions to some extent damaged the surface morphology of cellulose. However, as the damage was limited, the application of the obtained cellulose betainate as cationic adsorbent was not affected.

Optimization of the Preparation Conditions of Cellulose Betainate

To obtain cellulose betainate with high DS of cationic groups, the preparation conditions including reaction temperature, molar ratio of dicyandiamide to betaine hydrochloride, and reaction time were studied and the results are shown in Figure 4(a,b). (In this study, molar ratio of glucose unit of cellulose and betaine hydrochloride was kept at 1:1)

Figure 4(a) shows that with the increase of reaction temperature, DS of the product increased. That means higher temperature is beneficial for esterification. It can be seen if molar ratio of dicyandiamide to betaine hydrochloride was kept at 0.5:1, when the temperature was 130°C, DS of the product reached 0.54; when the temperature amounted to 150°C, DS as high as

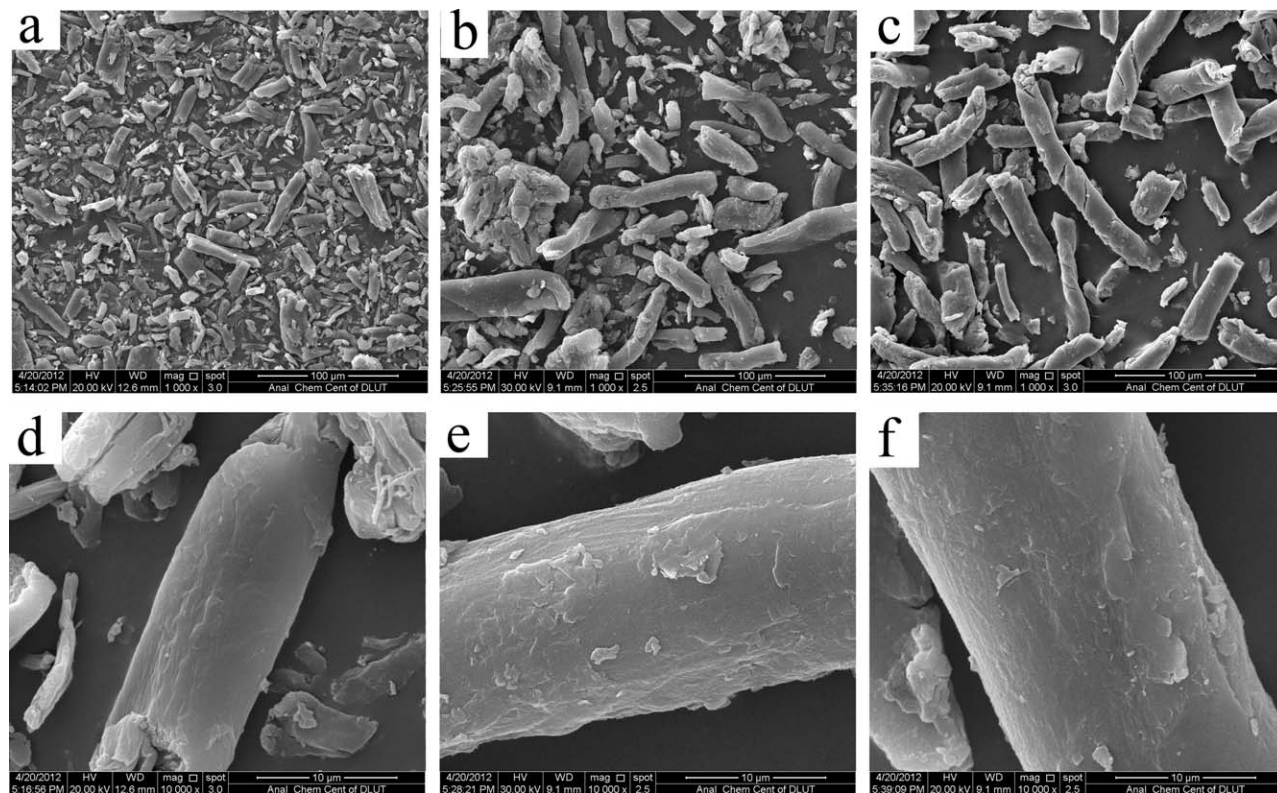


Figure 3. SEM photographs of (a,d) MCC, (b,e) alkali-treated cellulose, and (c,f) cellulose betainate under different magnifications.

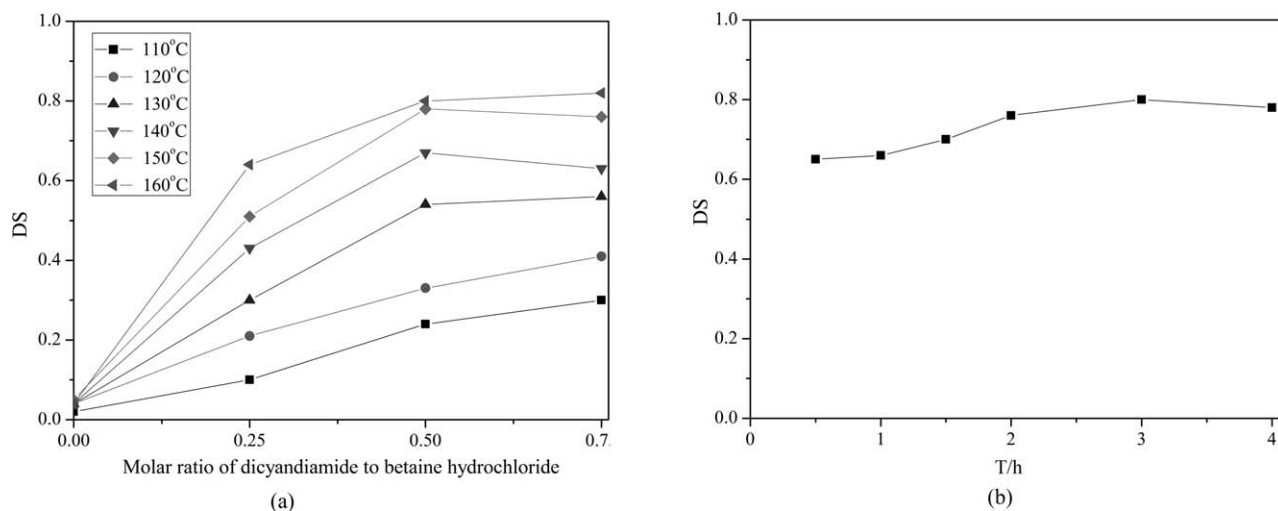


Figure 4. Effect of the (a) reaction temperature and molar ratio of dicyandiamide to betaine hydrochloride and (b) reaction time on DS of cellulose betainate.

0.80 could be achieved. With further increase of temperature to 160°C, slight increase of DS could be observed. In addition, it was found the color of the cationic product turned to be darker with the increase of the temperature. From Figure 4(a), it can also be observed that when the temperature kept at a constant value, DS mainly showed the tendency to increase with the increase addition of dicyandiamide. With the increase of molar ratio of dicyandiamide to betaine hydrochloride from 0.25 to 0.5, DS of the product increased obviously, whereas with further increase of the amount of dicyandiamide, DS increase was not distinct especially at temperature higher than 130°C.

Figure 4(b) shows the influence of reaction time on DS of the product. At 150°C and molar ratio of dicyandiamide to betaine hydrochloride kept at 0.5:1, DS could reach 0.65 for only 0.5 h's reaction. With the prolonging of the reaction time, DS increased gradually. When the reaction time was 3 h, DS of the cellulose betainate reached 0.80.

On the basis of the previous investigation, for achieving DS as high as 0.80, the reaction should be carried out at 150°C for about 3 h with a molar ratio of cellulose glucose unit, betaine hydrochloride to dicyandiamide of 1:1:0.5.

In addition, as dicyandiamide itself contains nitrogen, any effect of usage of dicyandiamide on measurement of the nitrogen content of the cationic cellulose should be avoided. So experiment (as described in "Preparation of cellulose betainate: Contrast experiment 2") was carried out without addition of betaine hydrochloride for investigation. Nitrogen content of the obtained cellulose was measured, and the results showed that nitrogen content of the cellulose before and after treatment with dicyandiamide was almost the same; it is 0.0009 and 0.001, respectively. The obtained results proved addition of dicyandiamide did not show any influence on the nitrogen content measurement of cellulose betainate.

Sorption Studies

In dye sorption study, two reactive dyes, RR 24 and RR 195, were used for comparison, and the effects of adsorbent (cellulose betainate) dosage and dye concentration on the sorption

properties of cellulose betainate were investigated. It can be clearly seen that RR 24 and RR 195 have similar structures, whereas RR 195 has larger planarity, more sulfonic acid groups and higher molecular weight compared with RR 24.

Effect of Adsorbent Dosage. Figure 5 presents the effect of adsorbent dosage (varying from 0.25 to 3 g/L) on R of HRR 24 and HRR 195 with C_0 of 100 mg/L. As shown in Figure 5, that R of both dyes increased with increasing adsorbent dosage and almost kept constant when the dosage of the adsorbent reached certain amount. Along with the increase of adsorbent dosage from 0.25 to 2.0 g/L, R of HRR 24 increased from 22.2% to 96.3% and further increase addition of the adsorbent to 3.0 g/L did not yield distinct increase in R of the dye. For removal of HRR 195, it was found 1.0 g/L of the adsorbent had already been effective and R could reach 93.1%, addition of 1.5 g/L of the adsorbent can further increase R to 95.7%. Adsorbent dosage for effective dye removal was affected by many factors including the dye concentration, the number of

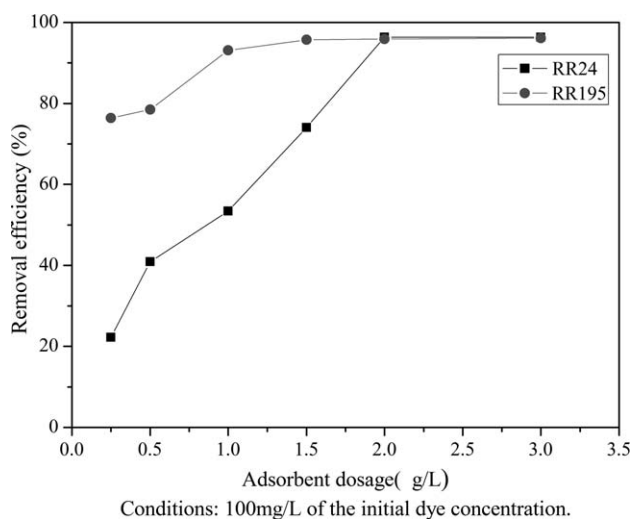


Figure 5. Effect of the adsorbent dosage on the R values of HRR 24 and HRR 195. Conditions: 100mg/L of the initial dye concentration.

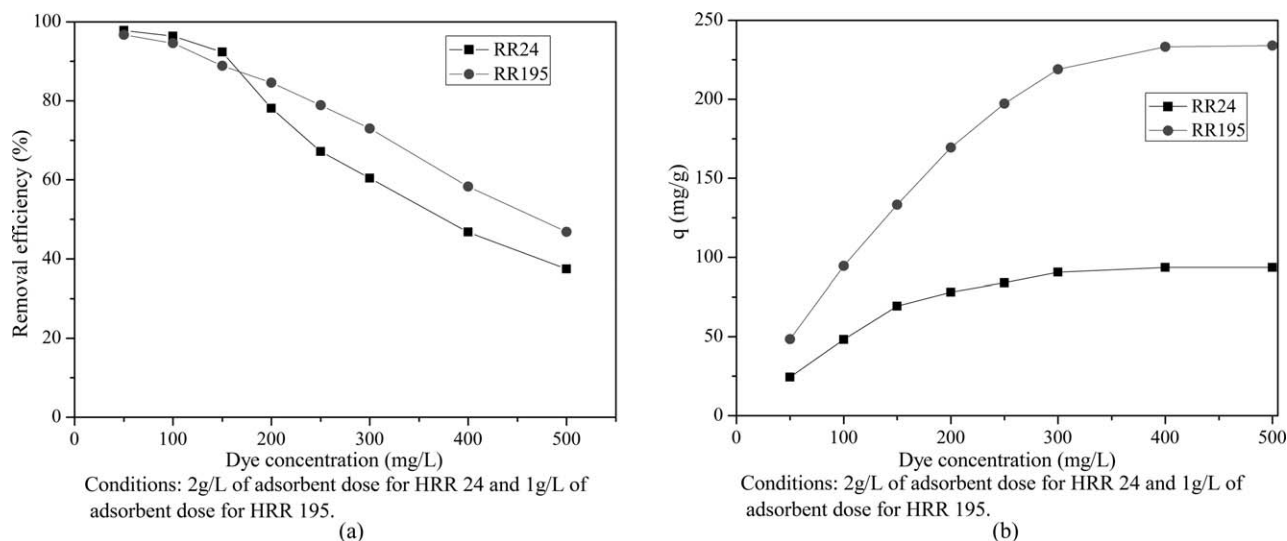


Figure 6. Effect of the dye concentration on the (a) R and (b) q values of HRR 24 and HRR 195.

anionic groups the dye contains, the planarity of the dyes, which determined the substantivity of the dyes to the adsorbents, etc. As HRR 195 has more anionic groups, sulfonic acid groups and larger planarity than HRR 24, it tends to be easily adsorbed on the cationic cellulose. That is considered to be the main reason for effective removal of HRR 195 with less adsorbent. It also can be deduced that for adsorption of the same amount of dyes, optimal adsorbent dosage is not the same due to the difference in dye structure. (Digital photos of cellulose betainate before and after dye adsorption, and adsorption effect of cellulose betainate have been taken and shown in Supporting Figures 3 and 4.)

Effect of the Dye Concentration. According to Figure 6(a), with the increase of dye concentration from 50 to 500 mg/L, R of all the dyes decreased gradually with the same amount of adsorbent. R of HRR 24 decreased from 97.8% gradually to 37.4% and that of HRR 195 from 96.7% to 46.8%. It can be calculated that the decrease amount was 60.4% and 49.9% for HRR 24 and HRR 195, respectively. This also indicated the adsorption capacity of the same adsorbent for different dyes was not the same. Figure 6(b) exhibited q of both dyes on cellulose betainate increased gradually with the increase of C_0 , which is mainly attributed to that the increase in dye concentration will increase the driving force of concentration gradient and accelerate the diffusion of the dyes from the solution on adsorbents.²⁸ It was also found when the dye concentration was larger than 400 mg/L, q almost kept at a constant value for both dyes, indicating reaching saturation adsorption of the dyes. Figure 6(b) also shows the saturation adsorption capacity of the adsorbent for HRR 195 was higher than 230 mg/g, whereas that for HRR 24 was much low, it is about 90 mg/g. Such difference in adsorption capacity was mainly owing to the structure difference between HRR 195 and HRR 24 as mentioned previously, that is HRR 195 has more anionic groups, sulfonic acid groups and larger planarity than HRR 24. Thus the cationic cellulose showed higher adsorption capacity for HRR 195.

Effect of the Salt Concentration. In the reactive dyeing process, inorganic salt, such as sodium chloride (NaCl) or sodium sul-

fate (Na_2SO_4) is usually added in dye bath to promote dye exhaustion. After dyeing, salt still remains in dye wastewater. Therefore, the influence of salt (NaCl) addition on adsorption capacity of HRR 24 was investigated and the results are shown in Figure 7. C_0 was 100 mg/L and adsorbent dosage was 2.0 g/L. It presented with the increase of salt addition from 0 to 0.5 mol/L, R decreased from 96.3 to 80.6%, which indicated that presence of salts diminished the performance of dye adsorption process distinctly. The adsorption of reactive dyes on the cationic cellulose occurred mainly through electrostatic attraction between the cationic groups in the cationic cellulose and the anionic groups in the dye molecules. When NaCl was added, the chlorine ions competed with the dye anions to adsorb on the cationic cellulose, so R decreased. The same results from salt addition were also obtained by other researches when the cationic adsorbents were used.²⁹ Therefore, it was better to treat salt first before adsorption of the dye wastewater with the cationic adsorbents.

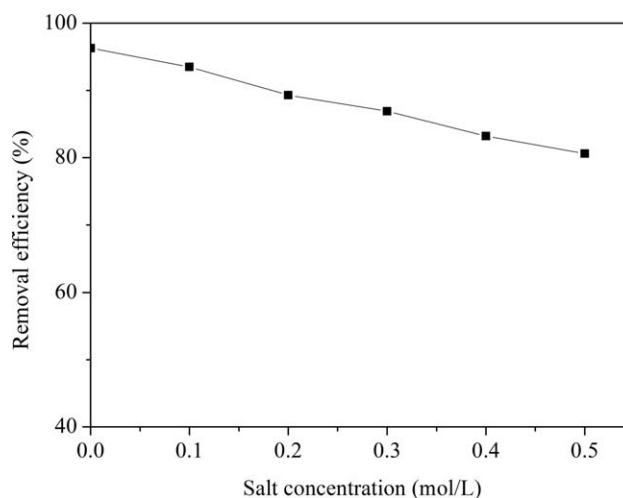


Figure 7. Effect of the salt concentration on the R values of HRR 24.

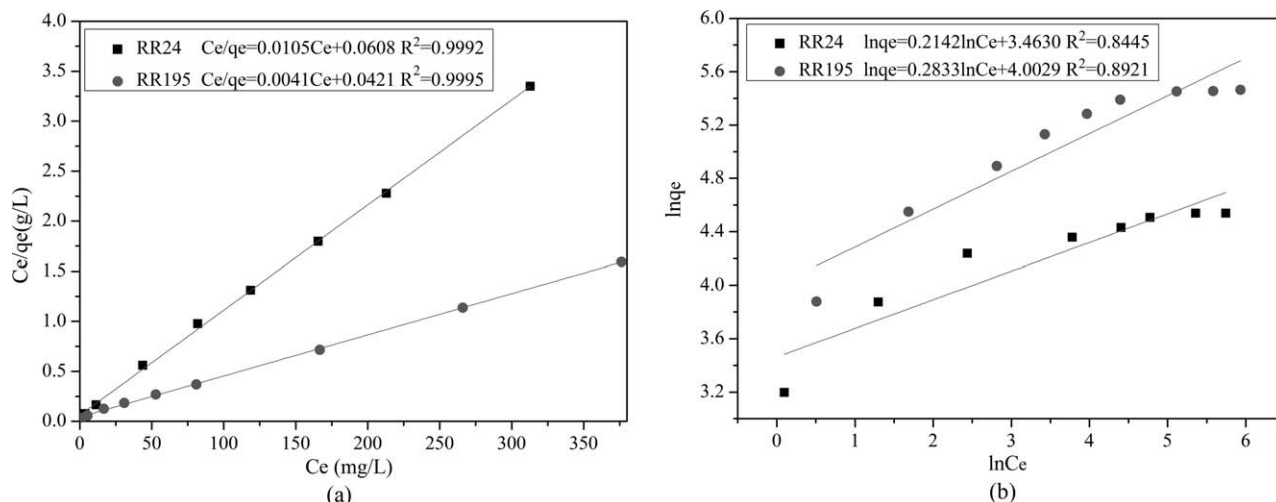


Figure 8. (a) Langmuir isotherm plots and (b) Freundlich isotherm plots for the adsorption of HRR 24 and HRR 195 on cellulose betainate.

Adsorption Isotherm. For interpretation of the adsorption behaviors, common isothermal adsorption equilibrium models, the Langmuir and Freundlich models, were applied to fit the experimental data.

Langmuir adsorption isotherm. A basic assumption of the Langmuir theory is that sorption takes place at specific homogeneous sites within the adsorbent. Theoretically, therefore, a saturation value is reached, beyond which no further sorption can take place. The saturated monolayer curve can be represented by the following expression:

$$q_e = \frac{Q_m b C_e}{1 + b C_e} \quad (4)$$

A linear form of this expression is

$$C_e/q_e = 1/(bQ_m) + (C_e/Q_m) \quad (5)$$

where C_e is the equilibrium liquid-phase concentration (mg/L); q_e is the amount of the dye adsorbed at equilibrium (mg/g); Q_m is a constant related to the area occupied by a monolayer of adsorbate, which reflects the maximum adsorption capacity (mg/g); and b is the Langmuir adsorption equilibrium constant (L/mg). From the data of C_e/q_e versus C_e , Q_m and b could be determined from the slope and intercept.

Figure 8(a) presents the Langmuir isotherm plots of HRR 24 and HRR 195 adsorption on cellulose betainate at room temperature. As shown in the graphs, the Langmuir isotherm fit well with the experimental data [correlation coefficient (R^2) > 0.999]. This indicates that the Langmuir adsorption theory was suitable for describing the adsorption of anionic dye on the adsorbent. On the basis of the Langmuir curve, the maximum adsorption capacities of HRR 24 and HRR 195 on the adsorbents were 95.2 and 243.9 mg/g, respectively.

Freundlich adsorption isotherm. The well-known Freundlich isotherm is a special case for heterogeneous surface energy, and the equation is given as follows:

$$q_e = Q_f C_e^{1/n} \quad (6)$$

The linear form of the Freundlich isotherm model is given by the following equation:

$$\ln q_e = \ln Q_f + \frac{1}{n} \ln C_e \quad (7)$$

where Q_f and n are both Freundlich constants.

As shown in Figure 8(b), the plot of $\ln q_e$ versus $\ln C_e$ did not give straight lines. The fact that both linear R^2 values were lower than 0.90 ($R^2 = 0.8445$ and 0.8921) showed poor agreement of the Freundlich isotherm with the experimental data.

This further confirmed that the electrostatic force played the major role in the interfacial interactions between both dyes and the adsorbent according to the basic hypothesis of the Langmuir isothermal adsorption.

CONCLUSIONS

Novel biomass-based cationic cellulose–cellulose betainate was efficiently prepared with a dry method. The characterization of the cationic cellulose showed that formation of ester bonds was observed in the FTIR spectrum, and small damage due to acidic and high-temperature reaction conditions was found on the cationic fibers. The increasing reaction temperature, prolonged reaction time, and increasing dosage of dicyandiamide were all good for enhancing the DS of the cationic group of the cellulose betainate. A DS of 0.80 was obtained under optimal conditions. The potential ability of the cationic cellulose for the treatment of reactive dye wastewater was investigated. Sorption studies indicated optimal sorption conditions, and the adsorption capacities of the cellulose betainate for HRR 24 and HRR 195 were different. This was mainly attributed to the difference in dye structures; this included the amount of sulfonic groups they contain, the molecular weight, the molecular planarity, and so on. Moreover, the existence of salt in the dye solution showed an adverse effect on the adsorption performance of the cationic adsorbent. Adsorption isotherm studies showed that the Langmuir isotherm model could well describe the adsorption of both dyes on the adsorbent and the calculated maximum

adsorption capacities for HRR 24 and HRR 195 were 95.2 and 243.9 mg/g, respectively.

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