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Structure and properties of β-cyclodextrin/cellulose hydrogels prepared in NaOH/urea aqueous solution

Lingzhi Zhang, Jinping Zhou*, Lina Zhang

Department of Chemistry, Wuhan University, Wuhan 430072, China

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ABSTRACT

β-Cyclodextrin (β-CD)/cellulose hydrogels were prepared in NaOH/urea aqueous solution by crosslinking with epichlorohydrin. The structure and morphology of the hydrogels were characterized with Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM). The swelling test, 5-fluorouracil (5-FU) and bovine serum albumin (BSA), and aniline blue (AnB) were used to investigate the swelling capability, drug release behavior and the fluorescent property of the hydrogels. The results indicated that the swelling degree and water uptake of the hydrogels decreased with an increase of the β-CD content. The *in vitro* release of 5-FU and BSA of the hydrogels showed an inclusion complex formed between 5-FU and β-CD. β-CD/cellulose hydrogels adsorbed AnB lead to a fluorescence enhancement attributing to the formation of the host-guest complex between β-CD and AnB.

1. Introduction

Hydrogel, the major component of the gel system, is defined as three-dimensional polymer networks swollen by aqueous solvent (Silva, Richard, Bessodes, Scherman, & Merten, 2009). They are structures mainly formed from biopolymers and/or polyelectrolytes, and contain large amounts of trapped water (Chang & Zhang, 2011). Recently, hydrogels based on cellulose and cellulose derivatives have been studied (Aouada, De Moura, Orts, & Mattoso, 2011; Basumallick, Ji, Naber, & Wang, 2009; Chang & Zhang, 2011; Mihranyan, Edsman, & Strømme, 2007). Blend hydrogels based on carboxymethylcellulose and carboxymethyl–chitosan, which were obtained by γ-irradiation, had high adsorption capacities for Pb and Au ions (Hiroki, Tran, Nagasawa, Yagi, & Tamada, 2009). Quantum dot-cellulose hydrogel obtained by chemical crosslinking in NaOH/urea system exhibited strong photoluminescence emission, and played an important role in the protection of the CdSe/ZnS structure (Chang, Peng, & Zhang, 2009). An antioxidant cellulose hydrogel prepared by introducing ferulic acid moieties onto cellulose backbone possessed an excellent antioxidant and radical scavenger activity (Trombino et al., 2009). Double-network hydrogels of bacterial cellulose and gelatin displayed high mechanical strength (Nakayama et al., 2004). As a typical soft matter, cellulose-based hydrogels can be used in the fields of dye removal (Yan, Shuai, Gong, Gu, & Yu, 2009), adhesion (Chen, Leung, Kroener, & Pelton, 2009), ion adsorption (Hiroki et al., 2009), cosmetic and pharmaceutical fields (Trombino et al., 2009), drug delivery (Fricain et al., 2002), tissue engineering (Vinatier et al., 2009), smart device (Saha, Manna, & Nandi, 2009) and so on.

Cyclodexrtins (CDs) are cyclic oligosaccharides consisting of six (α), seven (β), or eight (γ) glucose units linked by 1,4-α-glucosidic bonds from the enzymatic degradation of starch (Connors, 1997; Fayad, Marchal, Billaud, & Nicolas, 1997; Sabadini & Cosgrove, 2003; Szejtli, 1998). They have a shallow truncated cone shape and hydrophobic cavities those are nonpolar relative to their outer surface (Rusa, Luca, & Tonelli, 2001; Szejtli & Osa, 1996; Wenz, 1994). The sequestration of a hydrophobic molecule, or some part of it, inside the cavity results in the formation of noncovalent inclusion complexes (D'Souza & Lipkowitz, 1998; Merino, Junquera, J'Barbero, & Aicart, 2000; Szejtli & Osa, 1996). And as a result of complex formation, the characteristic properties of the included substance, such as solubility (Petrovic, Stojanovic, & Palic, 2011), chemical reactivity (Kato, Kakehata, Maekawa, & Yamashita, 2006), spectral properties (Wu et al., 2007) will be dramatically changed from those of either the parent molecule or the CDs. In recent years, CDs have been used extensively in analytical chemistry (Li & Purdy, 1992). An application for fluorescence enhancement is a process that has been studied over many years. For example, the enhanced fluorescence intensity of polydiacetylene by adding β-CD remained linear proportional to the temperature in the range from 25 °C to 80 °C, which could be applied as an accurate temperature sensor in chemical or bioenvironment (Chen, Jiang, Wang, Zou, & Zhang, 2010). Warfarin forms inclusion complexes with β-CD in aqueous media, and resulted in enhanced fluorescence of warfarin. Such

* Corresponding author. Tel.: +86 27 87219274; fax: +86 27 68754067.
E-mail address: zhoujp325@whu.edu.cn (J. Zhou).

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spectroscopic changes offer a venue for the development of bioanalytical methodologies for warfarin quantification in biological liquids (Vasquez, Vu, Schultz, & Vullev, 2009).

Cellulose is a most abundant polymer in nature and its derivatives are very popular because of their biocompatibility with tissues and blood, non-toxicity and low price. But to our knowledge, the studies about the hydrogels of cellulose and β-CD by chemical reactions have been reported scarcely. NaOH/urea aqueous solution has been found to be a good solvent for cellulose (Zhou & Zhang, 2000), and used to prepare into films (Liu et al., 2009), microspheres (Luo & Zhang, 2009), and hydrogels (Zhou, Chang, Zhang, & Zhang, 2007; Chang, Zhang, Zhou, Zhang, & Kennedy, 2010) in our laboratory. In this study, we synthesized cellulose hydrogels by the addition of β-CD crosslinked with epichlorohydrin (ECH) in NaOH/urea aqueous solution. Their structure and properties were characterized by Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), and swelling measurements. We also studied the different drug release behavior between 5-fluorouracil and bovine serum albumin, and the adsorption measurement and fluorescence emission of aniline blue by forming inclusion complexes, and hope to provide some valuable information as biological stains for dyes with β-CD/cellulose hydrogels.

2. Experimental

2.1. Materials

Cellulose (cotton linter pulp) was supplied by Hubei Chemical Fiber Group Ltd. (Xiangfan, China), and the viscosity-average molecular weight (M_η) of the cellulose was determined by viscometry in cadoxen (Brown & Wiskström, 1965) to be 7.8×10^4. Bovine serum albumin (BSA) with M_w of 6.7×10^4 g/mol was purchased from Sigma Chemical Corporation (USA). β-CD, 5-fluorouracil (5-FU), aniline blue (AnB), epichlorohydrin (ECH) and other reagents were purchased from Sinopharm Chemical Reagent Co., Ltd., China, which were of analytical grade and used without further purification.

2.2. Hydrogel preparation

Cellulose solution with the concentration of 4.0 wt.% was prepared according to the previous method (Zhang, Cai, & Zhou, 2005), and subjected to centrifugation at 7200 rpm for 15 min at 15 °C to exclude the slightly remaining undissolved part before using in further. β-CD was dissolved in 7 wt.% NaOH/12 wt.% urea aqueous solution with the concentration of 1.0, 2.0, 3.0 and 4.0 wt.%, respectively. β-CD/cellulose solutions were mixed in the ratio 50/50 (w/w), so the cellulose concentration was 2.0 wt.%, and the concentration of β-CD were 0.5, 1.0, 1.5 and 2.0 wt.%, respectively. Then, 10 mL ECH, as a crosslinking agent, was added dropwise to the β-CD/cellulose mixture within 30 min. After completion of ECH feeding, the resultant mixtures were stirred at room temperature for 30 min to become a homogeneous solution and then kept at 50 °C for 3 h in a water bath to obtain hydrogels. The weight ratio of β-CD and cellulose of the four hydrogels were 1/4, 1/2, 3/4, and 1/1, and coded as gel-1, gel-2, gel-3, and gel-4, respectively. The pure cellulose hydrogel was prepared from 2 wt.% cellulose solution, and coded as gel-0.

2.3. Characterization

FTIR spectra of β-CD and the hydrogels were performed with a Nicolet 170SX Fourier transform infrared spectrometer. The test specimens were prepared by the KBr-disk method. X-ray diffraction (XRD) pattern of the dried sheets was recorded on a XRD instrument (D8, BRUKER AXS GmbH, Karlsuhe, Germany) with Cu K_α radiation ($\lambda = 0.154$ nm). XRD data were collected from $2\theta = 5$ to 40° at a scanning rate of 2°/min.

The morphology observation of the hydrogels was carried out on a SEM instrument (Hitachi S-570, Japan). The hydrogels were swollen to equilibrium in distilled water at room temperature, then frozen in liquid nitrogen and snapped immediately, and freeze-dried before SEM observation. The fracture surface of the hydrogels were sputtered with gold, observed and photographed.

The UV–vis absorbance was measured by using a UV double beam spectrophotometer (UV-6100PCS, China). Fluorescence experiments were performed with the help of spectrofluorophometer (RF-5301 pc, Japan). The excitation wavelength was 313 nm, and the slit width was 5 nm.

2.4. Swelling measurements

To obtain the percentage of swelling (S_1%), the swollen hydrogels washed out NaOH and urea were weighed (W_{s1}) and then vacumm-dried at 50 °C. The S_1% is calculated as (Chang et al., 2010):

$$S_1\% = \frac{W_{s1}}{W_d} \times 100 \quad (1)$$

where W_d is the mass of the hydrogel at dry state.

The reswelling measurement was as following. The dry samples were incubated in distilled water for over 24 h at 25 °C to reach the swelling equilibrium. And the S_2% is calculated as:

$$S_2\% = \frac{W_{s2}}{W_d} \times 100 \quad (2)$$

where W_{s2} is the mass of the swollen hydrogel at 25 °C.

The vacuum-dried hydrogels were immersed in distilled water to rehydrate at 37 °C. The samples were removed from water at regular time's intervals. Before the weights of the hydrogels were recorded, the surfaces of the hydrogels had been wiped with filtered paper to remove water. The sample weights were recorded as the average value of three measurements. The results are expressed as water uptake (W_u), and it can be calculated as:

$$W_u\,(\%) = \frac{W_t - W_d}{W_{s1}} \times 100 \quad (3)$$

where W_t is the mass of the swollen hydrogel in distilled water at time t at 37 °C.

2.5. Drug loading and in vitro release

5-FU and BSA were chosen as the model drugs for controlled release by a swelling equilibrium method, respectively. 1 mg/mL 5-FU and 0.3 mg/mL BSA solution was prepared, and loaded into the hydrogel by placing the dried β-CD/cellulose hydrogel into the above solutions at 25 °C for 2 days to reach equilibrium state. Then the hydrogel was fetched out and vacuum-dried at 45 °C. The *in vitro* release was carried out at 37 °C in phosphate buffer solution (PBS, pH = 7.4). The release study was performed by immersing the above drug-loaded hydrogel in a glass bottle filled with PBS. Aliquots were withdrawn from the PBS periodically, the volume of PBS was held constant by adding fresh PBS every time. The concentrations of the drugs were measured by using a UV spectrophotometer at 266 nm for 5-FU and 278 nm for BSA. The loading capacity of 5-FU and BSA in the hydrogels was calculated as:

$$\text{Loading capacity(mg/mg hydrogel)} = \frac{M_0}{M_g} \quad (4)$$

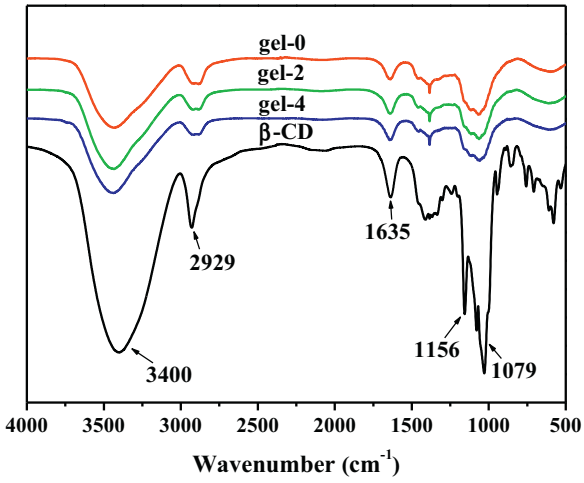


Fig. 1. FTIR spectra of β-CD and the β-CD/cellulose hydrogels.

And the cumulative release as a function of time (t) was calculated as:

$$\text{Cumulative release}(\%) = \frac{M_t}{M_0} \times 100 \quad (5)$$

where M_t is the mass of the drugs release from the hydrogel at time t, M_0 is the initial drug loaded in the hydrogel, M_g is the mass of hydrogel used for drug loading.

2.6. Adsorption of aniline blue and fluorescence enhancement

The swollen hydrogels were cut into cuboids with both the length and width of 1 cm. 2 g of the hydrogel strips were immersed into 8 mL of the AnB aqueous solution with the concentration of 0.04 mg/mL, and cultured for 1 day at room temperature to reach equilibrium state. Then the loading hydrogels and the remaining solutions (marked from sol-0 to sol-4, respectively) were measured by UV–vis and fluorescence spectrophotometers. The inclusion of β-CD stoichiometric ratio with AnB was determined by the fluorescent intensity performed by adding different contents of β-CD to the 0.04 mg/mL of AnB solution.

3. Results and discussion

3.1. Structure and morphology

The hydrogels with different content of β-CD were prepared in the NaOH/urea aqueous solution with ECH as a crosslinker. Plenty of hydroxyls both in cellulose and in β-CD were crosslinked with ECH, and thus forming hydrogel networks. This was a safe, environmentally friendly method to obtain a hydrogel.

Fig. 1 shows FTIR spectra of β-CD/cellulose hydrogels. The doughnut-shaped molecule of β-CD (for n glucose residues) has one rim lined with n primary hydroxyl groups, while the other rim lined with $2n$ secondary hydroxyl groups (Wenz, 1994), so it had strong absorption peaks at 3400 cm^{-1} (O—H), 2929 cm^{-1} (C—H), 1635 cm^{-1} (H—O—H bending), 1156 cm^{-1} (C—O), and 1079 cm^{-1} (C—O—C). After β-CD was introduced to the hydrogel, the absorption peaks of gel-2 and gel-4 at 1079 and 1156 cm^{-1} became weak compared to that of β-CD, and became a broad peak at around 1200 cm^{-1}. The strength of absorption peaks at 3400 and 1635 cm^{-1} diminished by the decrease of hydroxyl groups and hydrogen bonds after crosslinking, indicating that the crosslinking reaction between cellulose and β-CD by ECH were occurred in NaOH/urea aqueous solution.

Fig. 2 shows the SEM images of the swollen hydrogels. The cross-sections of the samples exhibited homogeneous porous architecture, indicating good miscibility between cellulose and β-CD. The average pore sizes of the chemical hydrogels kept almost constant with an increase of β-CD. The molecular size of β-CD (15.3 nm) (Petrovic, Stojanovic, & Palic, 2011) is very small compared to the pore size of pure cellulose hydrogel (about 10 μm), so the mesh structure of the β-CD/cellulose hydrogels roughly fall on the same size.

Fig. 3 displays the XRD patterns of β-CD and the hydrogels. The crystalline form of cellulose I (cotton linter) has typical diffraction peaks at 2θ around of 14.8°, 16.3°, and 22.6° (Isogai, Usada, Kato, Uryu, & Atalla, 1989). The strong crystalline peaks of β-CD are at 2θ around of 11.1°, 13.0°, and 18.3°. However, only a wide peak at around 2θ = 20–22° appeared in all of the hydrogels, which correspond to the (1 1 0) and (2 0 0) planes of cellulose II crystalline form. The diffraction peaks of β-CD disappeared in the gel matrix, indicating that β-CDs were in the amorphous phase. Besides, the peak intensity of β-CD/cellulose hydrogels is weak than gel-0, indicating a decrease of crystallinity with increasing β-CD content.

3.2. Swelling properties

The equilibrium swelling degree is an important parameter to evaluate hydrogels. Fig. 4a shows the swelling degree of β-CD/cellulose hydrogels in distilled water. The maximum swelling degree (S_1%) of gel-0 was nearly 7000. Equilibrium swelling degree of the hydrogels contained β-CD was lower than that of gel-0, and decreased with increasing content of β-CD. When the dry hydrogels were incubated in distilled water, the reswelling degree (S_2%) was markedly decreased than the swelling degree (S_1%). It was ascribed to the tightly shrinking porous structure of the samples after vacuum-drying; when the samples were incubated in distilled water, the pores of hydrogels could not recover to the original sizes. The reswelling degree decreased monotonically with increasing content of β-CD, because β-CD has a hydrophobic cavity which hinders the penetration of water molecules to the microporous hydrogels. But the influence on the swelling and reswelling degree was not changed a lot because of the much smaller size of β-CD compared to micropores of the matrix.

The vacuum-dried hydrogels were allowed to hydrate in distilled water at 37 °C to determine the water uptake. Fig. 4b illustrates the water uptake (W_u) curves for gel-0, gel-1, gel-2, and gel-4. Obviously, the swelling capability of the hydrogels increased with time, but after a certain period (approximately 650 min) the gels showed a constant swelling and an equilibrium swelling state was reached. However, the samples with different content of β-CD showed different water absorption capabilities. The water uptake of gel-1 before 250 min was higher than those of the other hydrogel samples. The more β-CD contained, the lower water uptakes were. After 650 min the swelling capabilities of all hydrogels kept constant, and had a low value of W_u compared to that of the pure cellulose gel because of the highly shrinking porous structures and the hydrophobic cavity of β-CD.

3.3. Drug loading and release behavior

Hydrogels have been used in controlled-release systems because of their good tissue compatibility and easy manipulation of swelling level and, thereby, solute permeability (Kim, Bae, & Okano, 1992). Herein, a hydrophobic anticancer drug, 5-FU and a hydrophilic protein, BSA, was chose as the mode drug to study the controlled-release behavior. The drug loading capacity of 5-FU and BSA in gel-0, gel-2 and gel-4 were 0.070, 0.089, 0.107 mg/mg and 0.061, 0.063, 0.062 mg/mg of the dried hydrogels, respectively. The loading capacities of 5-FU increased with an increase of β-CD

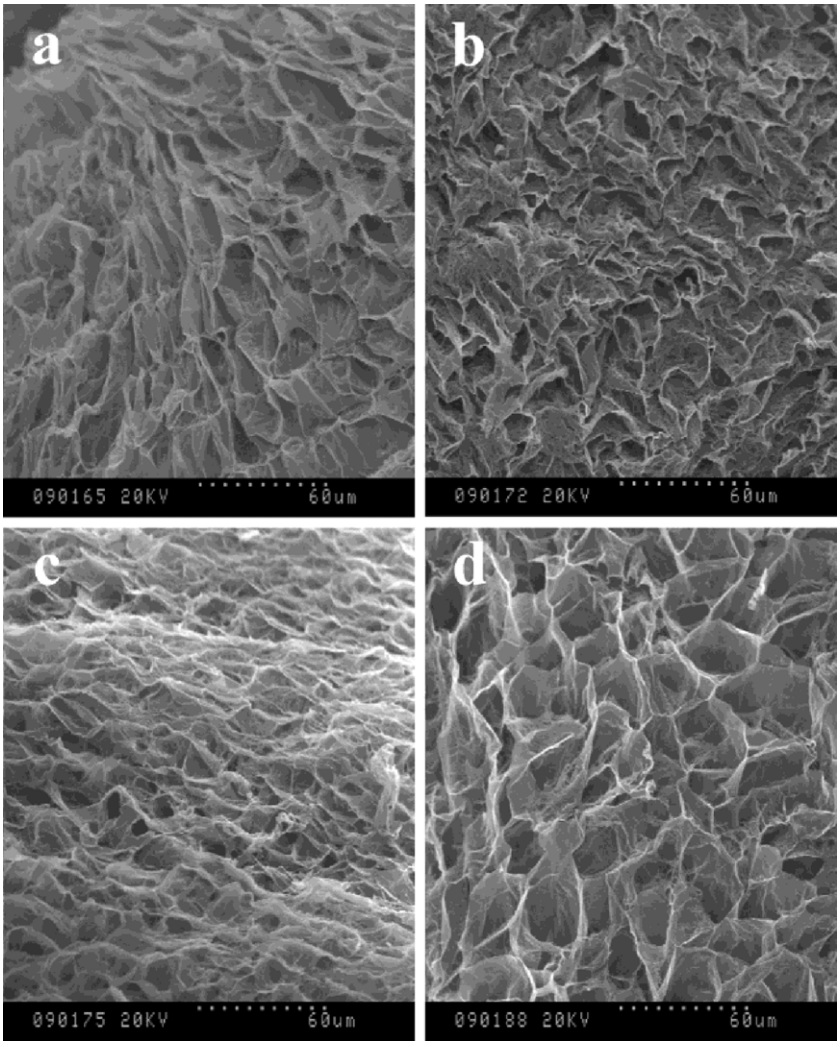


Fig. 2. SEM images of the β-CD/cellulose hydrogels: (a) gel-0, (b) gel-1, (c) gel-2, (d) gel-4.

content in the hybrid hydrogels, which was probably due to the formation of complexation of 5-FU and β-CD (Grosse, P. Bressolle, & Pinguet, 1998; Jin, Liu, Sun, Ni, & Wei, 2010). However, the loading capacities of BSA in gel-0, gel-2 and gel-4 are almost the same, which hardly changed with the incorporation of β-CD. The *in vitro* release of 5-FU and BSA is shown in Fig. 5. There was a burst release at the initial stage of 5-FU (Fig. 5a), which was ascribed to the quick dissolution of 5-FU from the surface of gels and diffusion out into the medium. As swelling continued, the drugs could be diffused out from the microporous matrix easily. About 100 min later, the *in vitro* drug release reached equilibrium. Due to the fact that the concentration of β-CD was arranged in a sequence of gel-4 > gel-2 > gel-0, the drug cumulative release was arranged in the reverse order. At 140 min, about 99% of 5-FU was released from gel-0. With an increase of β-CD content, the cumulative release slowed down sharply. The release of gel-2 after 140 min was 65% while that of gel-4 was 35%, which was ascribed to the host-guest complex formation between β-CD (host) and 5-FU (guest) (Grosse, P. Bressolle, & Pinguet, 1998; Jin et al., 2010). It was also confirmed that β-CD had been crosslinked in the cellulose hydrogel successfully, and the drug release of 5-FU was slowed down. However, the drug release of BSA was very slow (Fig. 5b), and seemed to be a diffusion process. A weak burst release was at the initial stage. The release rate of gel-0 and gel-2 was a little higher than that of gel-4 because of the lower crosslinking density of β-CD. It was seen that the release rate of the three hydorgels were almost the same after 30 h, and reached equilibrium after 50 h. Based on the results, the loading weight, release rate and cumulative release were influenced by the size of the drug molecule and the interaction between drug and β-CD. Besides, it is confirmed that the 5-FU/β-CD complex restrains the release from the hydrogels because the inclusion interactions are so strong to let 5-FU complex into the cavity of β-CD. Only the molecule such as adamantane which can form a stronger inclusion complex with β-CD (Goto, Furusho, & Yashima, 2007) was added into the system, 5-FU could be released from the cavity. Thus, the β-CD/cellulose hydrogels was not a good candidate for controlled release of 5-FU. However, the hydrogels still have many potential applications, such as pharmaceutical excipients, foods and cosmetics, separation, dye removal, fluorescence enhancement for imaging, and so on.

3.4. Fluorescence enhancement of β-CD/cellulose hydrogels

The cavity of β-CD was used to form a complex with some hydrophobic molecules; when a dye was captured, the spectral property would be changed (Wu et al., 2007). Firstly, inclusion complex formation causes changes in absorbance spectra of the dye, AnB, which was shown in Fig. 6a. AnB had strong peaks at 314 and 603 nm. After adsorption, a sharp decrease of the remaining solution at 603 nm was found once the hydrogels were immersed into it. And the absorbance at 603 nm was decrease from gel-0 to

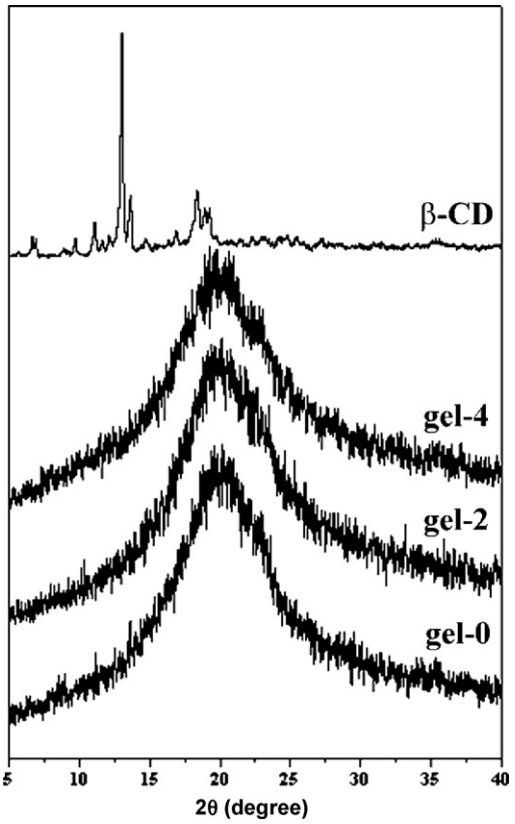


Fig. 3. XRD patterns of β-CD and the β-CD/cellulose hydrogels.

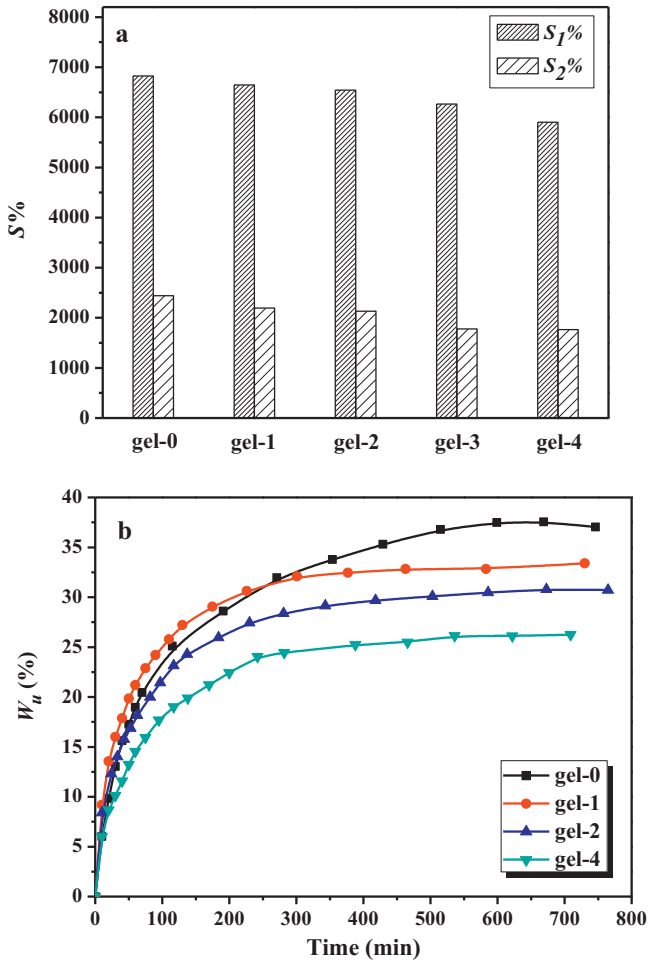


Fig. 4. (a) Swelling (S_1%) and reswelling (S_2%) degree of β-CD/cellulose hydrogels in distilled water. (b) Reswelling kinetics of the β-CD/cellulose hydrogels in distilled water at 37 °C.

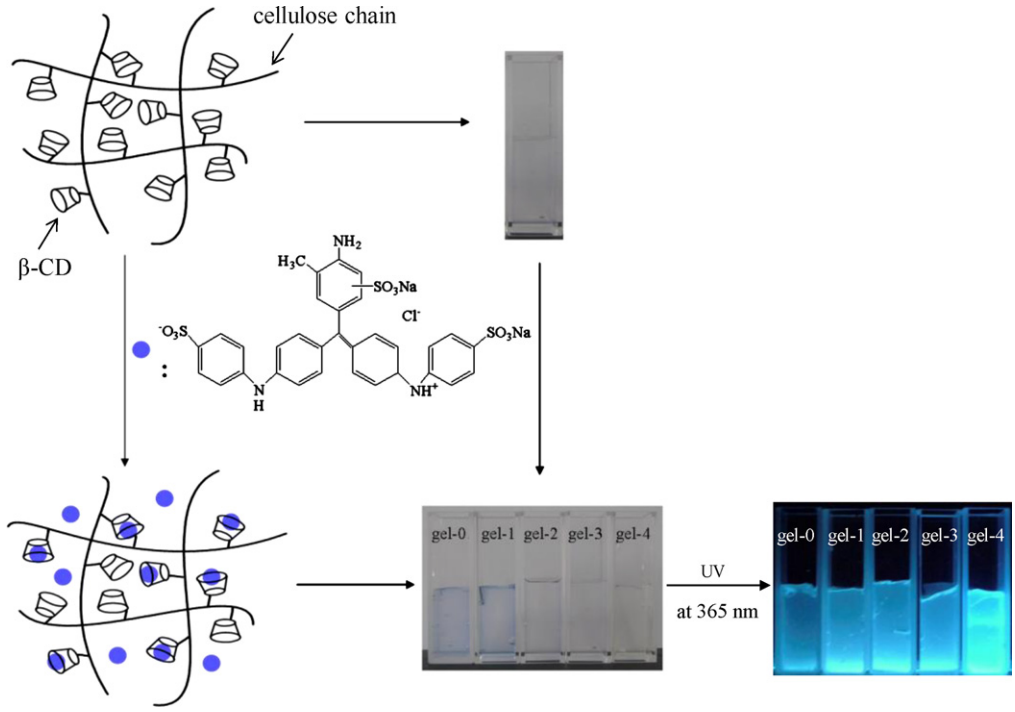
gel-4, which means some interactions existed between AnB and β-CD to cause an increase adsorption of gels as the increase content of β-CD. Meanwhile, the adsorption content of the wet hydrogels for AnB could be determined by the absorbance at 603 nm, which were 0.118, 0.139, 0.144, 0.147 and 0.154 mg/g of the dried hydrogel for gel-0, gel-1, gel-2, gel-3 and gel-4, respectively. Fig. 6b shows the absorbance spectra of the original AnB solution and the gels after loading with AnB. Peaks of the hydrogels at 314 nm increased with increasing content of β-CD, while a significant reduction at 603 nm was observed. And a red shift of 20 nm at the peak 314 nm was accompanied compared to the pure AnB solution. It is surprising that the increasing content of AnB in the hydrogels should cause an increasing absorbance at 603 nm, but in fact a decrease was observed. The addition of β-CD which yields the hypochromism was suggested to be due to the interaction of the electronic states of molecule with those of β-CD. And the red shift also supported some H-bonding interactions of AnB with β-CD. In other word, an inclusion complex was formed between AnB and β-CD.

Fig. 7a shows the fluorescence spectra of AnB with the increasing content of β-CD. On successive addition of β-CD, the spectrum increases significantly and exhibits hypsochromic shift. The blue shift in emission spectra indicates the formation of inclusion complex between AnB and β-CD. The high electron density of β-CD cavity induced the electron moves of the guest (AnB) to cause energy changes of excited state, and thus caused the hypsochromic shift and fluorescence enhancement. Information concerning the exact stoichiometry and arrangement of AnB in association with the β-CD molecule is crucial to the understanding of the mechanism of the inclusion between AnB and β-CD. Benesi–Hildebrand plots have been widely utilized to further characterize the stoichiometry and strength of association of β-CD/guest complex (Gorecki & Pawliszyn, 1996; Yu, Wei, Gao, & Zhao, 2002). The binding constant (K_b) for the inclusion complex could be calculated using the Benesi–Hildebrand equation (Gorecki & Pawliszyn, 1996; Hazra, Chakrabarty, Chabraborty, & Sarkar, 2004; Munoz de la Pena, Ndou, Zung, & Warner, 1991; Yu et al., 2002):

$$\frac{1}{I - I_0} = \frac{1}{K_b(I_1 - I_0)[\beta\text{-CD}]} + \frac{1}{I_1 - I_0} \quad (6)$$

where [β-CD] represents the analytical concentration of β-CD, K_b is the binding constant, I_0 represents the fluorescence intensity of free AnB, I_1 is the fluorescence intensity of the inclusion complex and I is the observed fluorescence intensity at its maximum. Inset of Fig. 7a shows a straight line from the plot of the $1/(I - I_0)$ *versus* reciprocal of the β-CD concentration for the present system, and the correlations were ≥0.996, indicating 1:1 stoichiometry in the AnB/β-CD inclusion complex.

Fig. 7b shows the fluorescent spectra of hydrogels adsorbed AnB. AnB can emit relatively weak fluorescence in the absence of β-CDs at 456 nm. When adsorbing AnB, the fluorescence intensity of hydrogels was markedly enhanced and the maximum emission wavelength shifted from 456 to 414 nm. As the content of β-CD increased in the gels, the intensity increased due to the interactions between β-CD and AnB. Scheme 1 illustrated the adsorption mechanism of the gels for AnB. When gel-0 was added to the AnB aqueous solution, the AnB molecule could enter into the homogeneous porous architecture of the hydrogel, leading to a color change (from colorless to blue) from naked eyes. For gel-1, AnB molecules would firstly enter into the porous structures of gels, following inclusion complexes formation between AnB



Scheme 1. Proposed mechanism for the adsorption of AnB in the hydrogels.

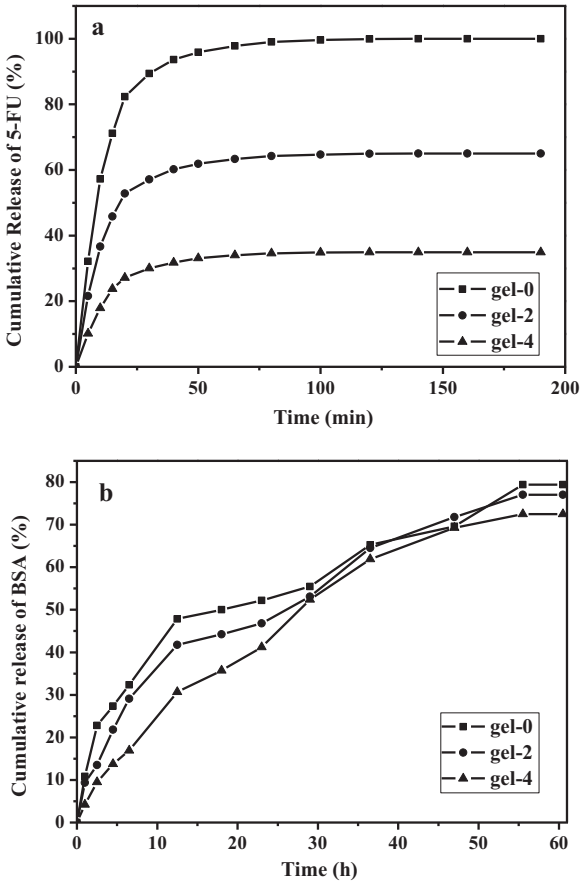


Fig. 5. Cumulative release of (a) 5-FU and (b) BSA from the β-CD/cellulose hydrogels at 37 °C.

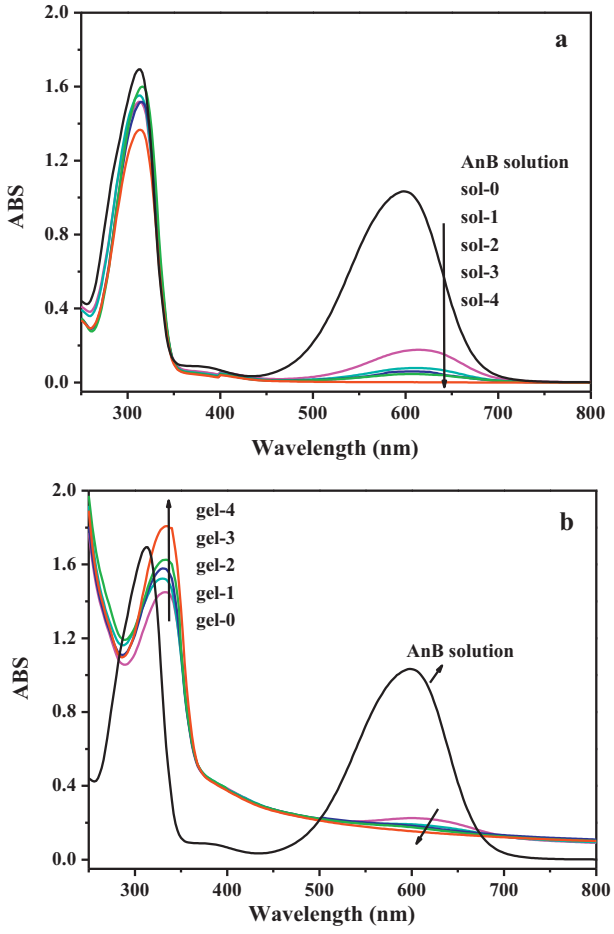


Fig. 6. (a) UV–vis spectra of the original AnB solution (5.42×10^{-5} mol/L) and the remaining solutions after adsorbing AnB by hydrogels, and (b) the absorbance spectra of the β-CD/cellulose hydrogels after adsorbing AnB.

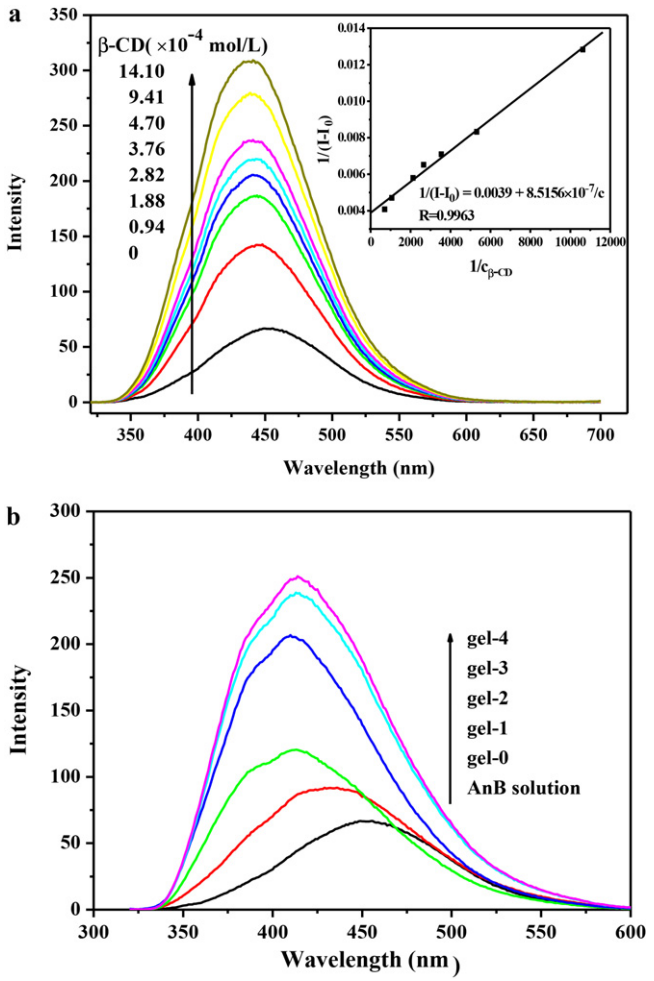


Fig. 7. (a) Fluorescence intensity of AnB solution (5.42×10^{-5} mol/L) with different concentration of β-CD, and the inset shows the Benesi–Hildebrand plots for 1:1 stoichiometry. (b) Fluorescence emission of the β-CD/cellulose hydrogels after adsorbing AnB.

and β-CD with the stoichiometry of 1:1. Gel-1 stilled exhibited a color of blue because a portion of AnB molecules were stilled kept in the porous structures of cellulose matrix. But as the content of β-CD increased, the excess AnB molecules kept in the porous architectures would gradually form AnB: β-CD complexes with the

color gradually changed to colorless again (gel-2, gel-3 and gel-4) with naked eyes. All of the samples exhibited a color of blue when radiating with an UV light at 365 nm. And the intensity increased from gel-0 to gel-4 (Scheme 1, right).

4. Conclusions

β-CD/cellulose hydrogels were successfully synthesized in NaOH/urea aqueous solutions by crosslinking with ECH. The results showed that β-CD was in the amorphous phase of the matrix. And the hydrogels exhibited a microporous structure and their pore sizes changed little with increasing β-CD content. The swelling degree and water uptake of the hydrogels decreased with an increase of the β-CD content. The difference of the drug release behavior between 5-FU and BSA was that a complex was formed for 5-FU with β-CD to inhibit the controlled release, while weak interactions were observed between BSA and β-CD. β-CD/cellulose hydrogels adsorbed AnB caused an enhanced fluorescence intensity due to the 1:1 host-guest complexion between β-CD and AnB. The hydrogels could be used as pharmaceutical excipients for some hydrophobic drugs which could complex with β-CD. And the fluorescence enhancement of the AnB-adsorbed β-CD/hydrogels would lead to the potential application as a biological stain.

Acknowledgements

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