Effect of algal flocculation on dissolved organic matters using cationic starch modified soils

Wenqing Shi, Lei Bi, Gang Pan*

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: shiwenqing2005320@126.com

*Corresponding author. E-mail: gpan@rcees.ac.cn, Telephone: +86 10 62849686, Fax: +86 10 62923541

Abstract: Modified soils are being increasingly used as geo-engineering materials for the sedimentation removal of cyanobacterial blooms. However, when organic flocculants were used as soil modifiers, little is known about the potential impacts of these materials on the treated water. This study investigated dissolved organic matters in the bloom water after algal removal using cationic starch modified soils (CS-MS). Results showed that the dissolved organic carbon (DOC) could be decreased by CS-MS flocculation and the use of higher charge density CS yielded a greater DOC reduction. When CS with the charge density of 0.052, 0.102 and 0.293 meq/g were used, dissolved organic carbon (DOC) was decreased from 3.4 to 3.0, 2.3 and 1.7 mg/L, respectively. The excitation-emission matrix fluorescence spectroscopy and UV_{254} analysis indicated that CS-MS exhibits an ability to remove some soluble organics, which contributed to the DOC reduction. However, the use of low charge density CS posed a potential risk of DOC increase due to the high CS loading for effective algal removal. When CS with the charge density of 0.044 meq/g was used, DOC was increased from 3.4 to 3.9 mg/L. This study suggested that by optimizing charge density of CS, the use of organic MS-CS flocculants can achieve the sedimentation removal of cyanobacterial cells without increasing the content of dissolved organic matters in bloom waters. For the settled organic matters, other measures (e.g., capping treatments using oxygen loaded materials) should be jointly applied after algal flocculation.

Keywords: Cyanobacterial bloom; Cationic starch; Modified soil; Charge density; Dissolved organic carbon

Introduction

The frequent outbreak of cyanobacterial blooms in eutrophic waters is a global issue, posing serious threats to aquatic ecosystem and human health (Chen et al., 2006; Liu and Le, 2015; Lu et al., 2013; Wang et al., 2013c). Modified soils (MS) have triggered great interest as geo-engineering materials for cyanobacterial bloom control in recent years (Lürling and van Oosterhout, 2013; Mackay et al., 2014; Spears et al., 2014; Tian et al., 2014). In this method, modifiers offer soil particles the abilities of

charge neutralization and bridging, and make them obtain flocculation potential for cyanobacterial cells (Li and Pan, 2013; Pan et al., 2011a).

Several chemical coagulants (e.g., aluminum and ferric salts) and organic macromolecular flocculants (e.g., cationic starch, chitosan and *Moringa oleifera*) have been tested as soil modifiers for algal removal (Dai et al., 2015; Li and Pan, 2013; Pan et al., 2006; Shi et al., 2015). Compared with chemical modifiers, natural polymers are often easily biodegradable, eco-friendly and are well accepted by the public (Mukherjee et al. 2014; Ndabigengesere and Narasiah, 1998; Renault et al., 2009). However, when organic flocculants are sprayed into natural waters, a major concern is the likelihood of dissolved organic matter (DOM) increase in water column. The DOM is a storage pool of nitrogen and phosphorous and an important contributor of biochemical/chemical oxygen demand in eutrophic waters (Bushaw et al., 1996; Qu et al., 2013). The increase of DOM may result in the lost of water quality and the rapid oxygen depletion in receiving water (Evans et al., 2005; Mermillod-Blondin et al., 2005). On the other hand, with the operation of charge neutralization, some autochthonous soluble organic matters may be simultaneously flocculated and settled during algal flocculation using the positively charged MS (Lee and Westerhoff, 2006; Wang et al., 2013b), and DOM reduction may occur after algal removal. However, to date, the use of organic flocculants in MS has mainly focused on algal removal effect with little consideration of its impacts on DOM in the treated bloom water.

Algae particles are negatively charged, which can stably suspend in water column (Chen et al., 2004). Charge neutralization is a main mechanism operating algal flocculation using MS, which can reduce the electrostatic repulsion and promote aggregation between MS and algae particles (Li and Pan, 2013; Shi et al., 2015). To achieve the effective algal removal, desired amount of positive charges need be provided to neutralize negative charges on algal cell surface (Li and Pan, 2015; Li et al., 2015). Thus, the charge density may potentially affect the loadings of modifiers, which are directly related to the residual DOM in the treated water. Indentifying and understanding of this effect is essential to control DOM content in MS treated bloom water and develop new soil modifiers for cyanobacterial bloom mitigation.

In this study, a series of cationic starch (CS) with different charge densities were used as soil modifiers (CS-MS). The flocculation of *Microcystis aeruginosa* (*M. aeruginosa*) using each CS-MS were conducted by jar tests. Dissolved organic carbon (DOC), UV absorbance at 254 nm (UV_{254}) and excitation-emission matrix (EEM) fluorescence spectra were used to analyze the DOM after algal removal. The objective of this study is to explore the effect of algal flocculation on DOM in bloom waters using CS-MS.

1. Materials and methods

1.1. Algal species and culture

M. aeruginosa, a common freshwater bloom-forming cyanobacterium, was used in this study. The *M. aeruginosa* cells (FACHB-905) were obtained from the Institute of Hydrobiology, Chinese Academy of Sciences, and cultivated in BG11 medium. The BG11 medium was composed of 1,500 mg/L $NaNO_3$, 75 mg/L $MgSO_4 \cdot 7H_2O$, 40 mg/L K_2HPO_4, 36 mg/L $CaCl_2 \cdot 2H_2O$, 20 mg/L Na_2CO_3, 6 mg/L Citric acid monohydrate, 6 mg/L Ferric ammonium citrate, 2.86 mg/L H_3BO_3, 1.86 mg/L $MnCl_2 \cdot 4H_2O$, 1 mg/L Na_2EDTA, 0.39 mg/L $Na_2MoO_4 \cdot 2H_2O$, 0.22 mg/L $ZnSO_4 \cdot 7H_2O$, 0.08 mg/L $CuSO_4 \cdot 5H_2O$, 0.05 mg/L $Co(NO_3)_2 \cdot 6H_2O$. Algal batch cultures were maintained at 25 ± 1℃ under continuous cool white fluorescent light of 2,000-3,000 lux on a 12 h light and 12 h darkness regimen in an illuminating incubator (LRH-250-G, Guangdong Medical Apparatus Co. Ltd., China).

1.2. Cationic starch modified soils

CS was prepared by reacting corn starch (Unilever Co. Ltd., China) with cationic monomer, 2,3-epoxypropyl trimethyl ammonium chloride (GTA), using the microwave-assisted method (Lin et al., 2012). The details of the synthesis are as follows: 0.5 g GTA was dissolved in 100 ml of 5.0 g/L NaOH solution with constant stirring for 10 min. 10.0 g starch was added to the above mixture and stirring was continued for another 30 min at a 70℃ water-bath. Then, the reaction vessel was placed on the turntable of a domestic microwave oven (Guangdong Galanz Group Co. Ltd., China) and irradiated at the power of 750 W with periodic pause to avoid boiling. This microwave irradiation-cooling cycle was continued until a viscous gel-like mass

formed. After cooled down to room temperature, the gel-like mass was washed with ethanol for three times, dried in a vacuum oven (DZF-6020, Shanghai Yiheng Instrument Co. Ltd., China) at 50℃ for 6 h and then pulverized before use. The obtained product is termed $CS_{0.5:10}$ (0.5:10 is the mass ratio of GTA to starch). Using this method, $CS_{1.0:10}$, $CS_{1.5:10}$ and $CS_{2.5:10}$ were synthesized. As the mass ratio of GTA to starch increased, the charge density and degree of substitution of CS increased, but the intrinsic viscosity and molecular weight showed no significant changes (T-test, $P < 0.05$) (**Table** 1).

Table 1 The properties of cationic starch

	Charge density[a] (meq/g)	Degree of substitution[b]	Intrinsic viscosity[c] (dL/g)	Molecular weight[d] ($\times 10^5$)
Native starch	0	0	1.21	4.27
$CS_{0.5:10}$	0.044	0.073	1.31	4.67
$CS_{1.0:10}$	0.052	0.092	1.24	4.39
$CS_{1.5:10}$	0.102	0.166	1.30	4.63
$CS_{2.5:10}$	0.293	0.255	1.08	3.76

[a] Determinated using the polyelectrolyte titration method (Kam and Gregory 1999).

[b] Determinated using one point method (Ahmad et al. 1999).

[c] Determined using element analysis method (Lin et al., 2012).

[d] Calculated based on the Mark-Houwink relationship taking 'k' as 1.18×10^{-3} and 'a' as 0.89 (Ahmad et al. 1999).

The soil used was collected from the bank of Meiliang Bay, Lake Taihu (China). This bay has suffered from severe cyanobacterial blooms over the past years, and MS materials have been tested to settle the blooms (Pan et al., 2006; Pan et al., 2011b). The soil sample was grounded and sieved (180 meshes) before use. For CS-MS preparation, a certain amount of CS was used to modify the soil suspension according to the dose conditions tested. The soil concentration used in all the flocculation experiments was fixed to 100 mg/L. The surface charge of soil and CS-MS particles

was characterized using a Zetasizer 2000 (Malvern Co. United Kingdom).

1.3. Algal flocculation

Flocculation experiments were conducted in a jar test apparatus (ZR3-6, Zhongrun Water Industry Technology Development Co. Ltd., China) using *M. aeruginosa* cultures in mid- to late-exponential growth phase. The initial cell concentration for all the flocculation experiments was set to 3.2×10^9 cells/L. 200 ml of readily prepared *M. aeruginosa* solution was transferred to 300-ml beaker, and then stirred at 200 r/min for 1 min and 40 r/min for another 5 min after CS-MS was added. The control was run in the above mentioned *M. aeruginosa* solution without adding any soil or CS. The flocculation experiments were conducted at raw algal solution pH of 8.60. The pH kept at 8.60 ± 0.2 after the addition of CS-MS. All the flocculation experiments were conducted in triplicate.

Samples were collected from 2 cm below the water surface after floc sedimentation for 30 min to enumerate the cell number using an Axioskop 2 mot plus microscope (Carl ZEISS, Germany). The algal removal efficiency was calculated as: (initial cell concentration - sample cell concentration) / initial cell concentration × 100%. After algal flocculation, 10 ml water sample was also collected to investigate the cell surface charge using a Zetasizer 2000 (Malvern Co. United Kingdom).

1.4. DOM analysis

DOM analysis was performed after algal sedimentation by measuring DOC, UV_{254} and EEM spectra. Water samples were filtered through 0.45-μm membrane filters before analysis. DOC was measured using a TOC analyzer (Liqui TOC II, Elementar, Germany). UV_{254} was determined using an UV-Vis spectrophotometer (756PC, Shanghai Sunny Hengping Scientific Instrument Co. Ltd., China) at 254 nm with a quartz cell path of 1 cm. The EEM spectra were measured using a fluorescence spectrophotometer (F-7000, Hitachi High-Tech. Corp., Japan). The spectra were collected with subsequent scanning emission spectra from 250 to 550 nm at 5 nm increments by varying the excitation wavelength from 200 to 400 nm at 5 nm increments. The excitation and emission slits were maintained at 5 nm and the scanning speed was set at 1000 nm/min. The spectrum of pure water was used as the

blank.

2. Results

2.1. Surface charge of CS-MS particles

After CS modification, the isoelectric point of soil particles was remarkably increased from pH 0.5 to above pH 10.8 (**Fig. 1A**), which made CS-MS particles positively charged under most natural water conditions. However, the surface charge of CS-MS particles varied with the charge density of CS. When high charge density CS was used, CS-MS particles possessed high surface charge (**Fig. 1A**) and gained a high ability of charge neutralization under natural water conditions. When 21 mg CS-MS (20 mg soil modified with 1 mg CS) was added to 200 ml *M. aeruginosa* solution with 6.4×10^8 cells, an increase was caused in the surface charge of algal cells (**Fig. 1B**). The cell surface charge was neutralized and increased from -37.5 mV to -33.0, -29.8, -20.2 and +1.2 mV in $CS_{0.5:10}$-MS, $CS_{1.0:10}$-MS, $CS_{1.5:10}$-MS and $CS_{2.5:10}$-MS treatments, respectively (**Fig. 1B**).

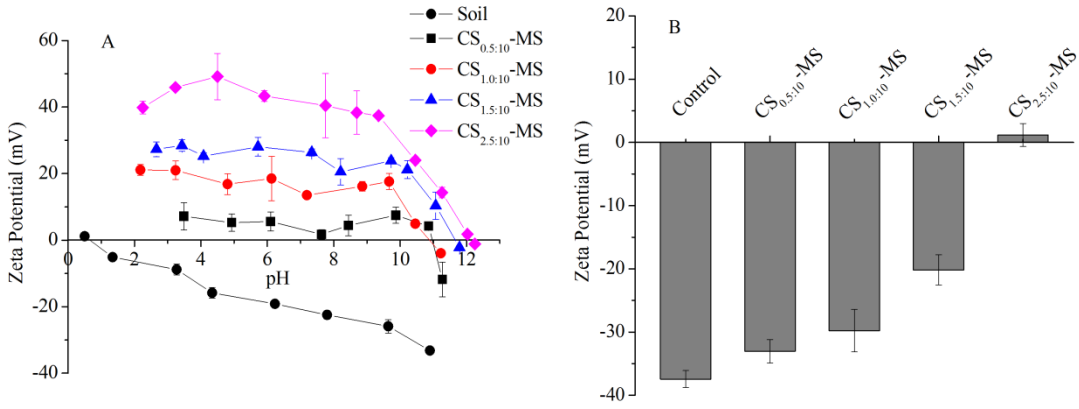

Fig. 1 – Surface charge of soil particles after CS modification (A) and the increase of *M. aeruginosa* surface charge after the addition of CS-MS (B). Error bars indicate standard deviations.

2.2. Algal flocculation using CS-MS

After CS-MS was added, a maximum removal efficiency of about 85% for *M. aeruginosa* cells was achieved, but the optimal CS dosage varied greatly depending on its charge density, which was 60, 40 and 15 mg/L for $CS_{0.5:10}$, $CS_{1.0:10}$ and $CS_{1.5:10}$, respectively. In $CS_{2.5:10}$-MS treatment, the removal efficiency just maximally reached

76% at the CS dosage of 5 mg/L (**Fig. 2A**). Once CS was overdosed, the removal efficiency exhibited a deceasing trend (**Fig. 2A**). As the CS dosage further increased to 80 mg/L, the removal efficiency gradually decreased to 81%, 66% and 31% in $CS_{0.5:10}$-MS, $CS_{1.0:10}$-MS and $CS_{1.5:10}$-MS treatments, respectively; in contrast, the removal efficiency in $CS_{2.5:10}$-MS treatment dropped sharply and reached less than 10% at the 80 mg/L of CS (**Fig. 2A**). The surface charge of algal cells as a function of CS dosage was measured. As the CS dosage increased, the cell surface charge was increased and charge reversal occurred around the optimal dosage of CS (**Fig. 2B**). At the 80 mg/L of CS, the cell surface charge reached +4.4, +8.9, +15.6 and +26.4 mV in $CS_{0.5:10}$-MS, $CS_{1.0:10}$-MS, $CS_{1.5:10}$-MS and $CS_{2.5:10}$-MS treatments, respectively (**Fig. 2B**).

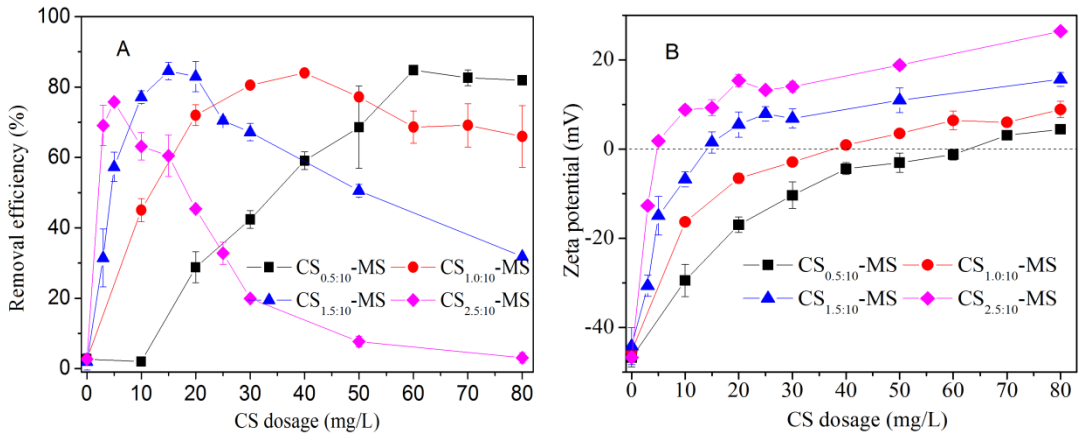

Fig. 2 – Algal removal efficiency and surface charge of algal cells at different dosage of CS. The soil concentration was fixed to 100 mg/L. Error bars indicate standard deviations.

2.3. DOC and UV_{254}

After algal removal, the DOC in algal solution showed a decrease and the use of higher charge density CS yielded a greater DOC reduction. The DOC was decreased from 3.4 to 3.0, 2.2 and 1.7 mg/L in $CS_{1.0:10}$-MS, $CS_{1.5:10}$-MS and $CS_{2.5:10}$-MS treatments, respectively. However, the use of low charge density CS resulted in the DOC increase after algal removal. The DOC in $CS_{0.5-10}$-MS treatment was increased from 3.4 to 3.9 mg/L (**Fig. 3**). The UV_{254} reduction was observed in all the treatments, which was enhanced by higher charge density CS. After algal removal, the UV_{254} was

decreased from 0.16 to 0.14, 0.11, 0.10 and 0.08 in $CS_{0.5:10}$-MS, $CS_{1.0:10}$-MS, $CS_{1.5:10}$-MS and $CS_{2.5:10}$-MS treatments, respectively. The soil-only treatment could also lead to limited DOC (from 3.4 to 2.8 mg/L) and UV_{254} (from 0.16 to 0.15) reductions in algal solution (**Fig. 3**).

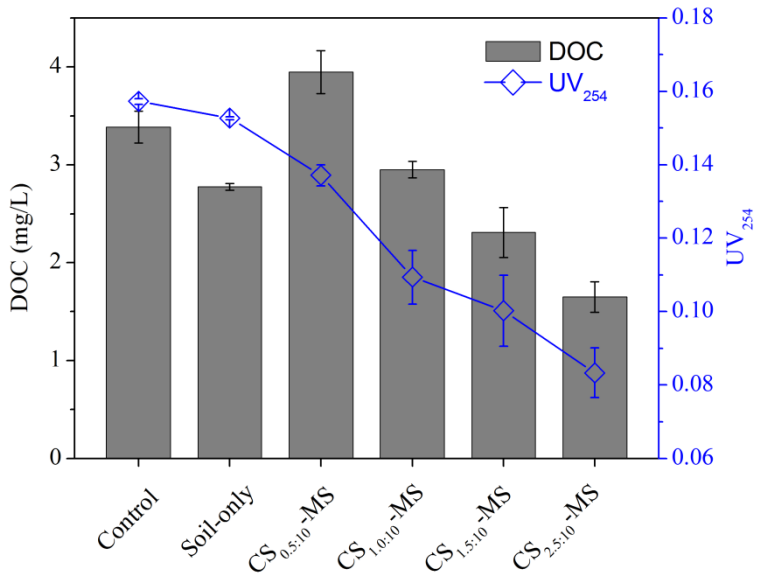

Fig. 3 – The changes of DOC and UV_{254} in algal solution after algal removal at the optimal dosage of CS. The soil concentration was fixed to 100 mg/L. Error bars indicate standard deviations.

2.4. EEM fluorescence spectra

One main peak at 270-285/320-345 nm (Ex/Em) was observed from the EEM fluorescence spectra of algal solution (**Fig. 4**), which were identified as soluble microbial by-product-like organics, including tyrosine-, tryptophan and protein-like components (Osburn et al., 2012; Guo et al. 2010). After algal removal, the peak intensity showed a decrease, suggesting that the soluble organics were removed by CS-MS during flocculation-sedimentation process. The removal of these organics was enhanced by CS with the higher charge density (**Fig. 4**). When $CS_{0.5:10}$, $CS_{1.0:10}$, $CS_{1.5:10}$ and $CS_{2.5:10}$ were used in MS, the peak intensity was decreased from 110.4 to 98.5, 78.5, 73.1 and 33.9, respectively. In soil-only treatment, the peak intensity was also decreased to 80.2 (**Fig. 4**).

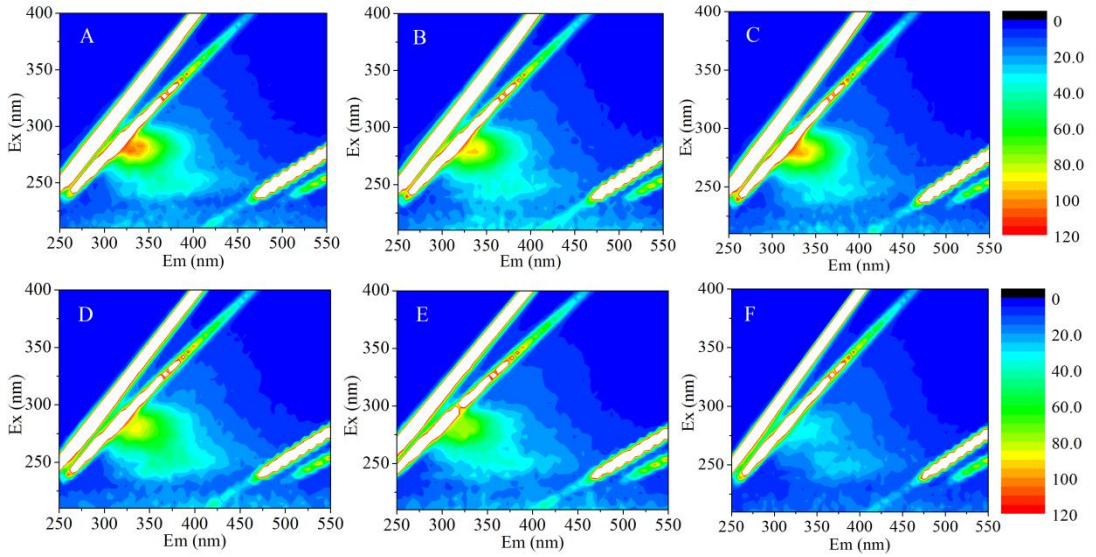

Fig. 4 – EEM fluorescence spectra of algal solution after algal removal using CS-MS. (A) Control, (B) Soil-only, (C) $CS_{0.5:10}$-MS, (D) $CS_{1.0:10}$-MS, (E) $CS_{1.5:10}$-MS, (F) $CS_{2.5:10}$-MS.

3. Discussion

3.1. Charge density and the optimal dosage of CS

Charge neutralization is essential in creating algal flocculation potential by eliminating energy barrier for the aggregation between flocculants and algae particles (Liu et al., 2010; Phoochinda et al., 2004). When CS with the higher charge density was used, CS-MS particles possessed the higher surface charge (**Fig. 1A**) and gained a higher ability of charge neutralization (**Fig. 1B**). The optimal algal flocculation occurred around the point of total charge neutralization (zeta potential close to zero, **Fig. 2B**). Thus, CS-MS with the higher charge neutralization ability achieved effective algal removal at a lower CS loading, simply because, for a given dosage, they can deliver more positive charges to the cell surface. At the soil concentration of 100 mg/L, the optimal CS dosage for the removal of 3.2×10^9 *M. aeruginosa* cells/L followed the order of $CS_{0.5:10} > CS_{1.0:10} > CS_{1.5:10} > CS_{2.5:10}$, which was 60, 40, 15 and 5 mg/L, respectively (**Fig. 2A**).

Based on the dosage and charge density of CS, algal removal efficiency and cell surface charge are re-plotted against positive charges in **Fig. 5**. It further indicated that positive charges play a key role in algal flocculation and the data sets take on a

similar shape in each CS-MS treatment. As the positive charge dosage increased, algal removal efficiency increased and reached the maximum at the charge dosage of 0.9 $\times 10^{-12}$ meq/cell. The cell surface charge was simultaneously increased from -46.2 to 0 mV. Once positive charges were overdosed, the removal efficiency decreased, since the reversal of cell surface charge (**Fig. 2B**) potentially reintroduced the electrostatic repulsion and prevented aggregation between CS-MS and algae particles (Jangkorn et al. 2011; Mosse et al., 2012; Shi et al., 2015). Hence, to achieve effective algal removal using MS, the modifier loading mainly depended on the charge density. The loadings of low charge density organic modifiers are often high to provide enough positive charges, which potentially introduce substantial amount of organic matters into the receiving water. It is important to notice that flocculants with excessively high charge density are either not recommended to be used as soil modifiers. The low modifier loadings can not offer adequate macromolecular chains for bridging effect in algal flocculation and may lead to limited algal removal (e.g., $CS_{2.5:10}$ in **Fig. 2A**) (Li and Pan, 2013; Zou et al., 2005). Additionally, a small change in the loading of high charge density modifier can lead to significant differences in the amount of positive charges provided, which results in a narrow dosage range for effective algal removal (e.g., $CS_{2.5:10}$ in **Fig. 2A**). This hinders the application of MS in fields where precise dosage control is often difficult.

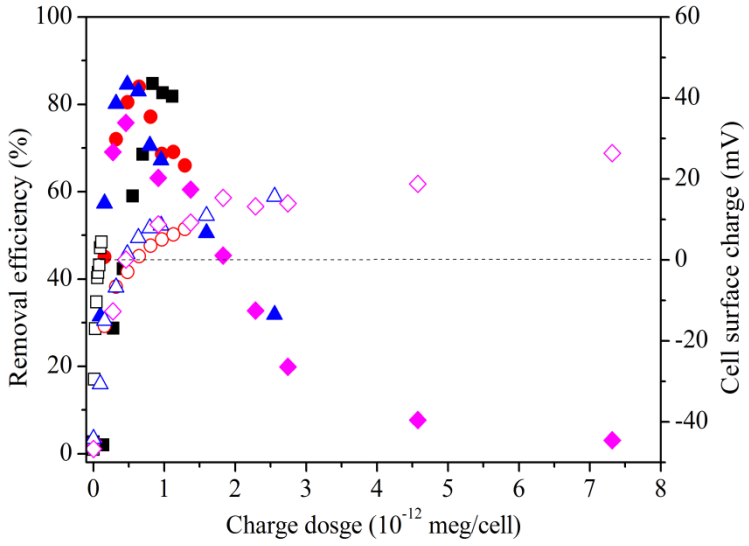

Fig. 5 – Algal removal efficiency and cell surface charge at different dosage of

positive charge. The closed and open symbols represent algal removal efficiency and cell surface charge, respectively. $CS_{0.5:10}$-MS (squares), $CS_{1.0:10}$-MS (circles), $CS_{1.5:10}$-MS (triangles), $CS_{2.5:10}$-MS (diamonds).

3.2. DOM after algal removal

One main aim of algal removal is to prevent the occurrences of water quality deterioration and oxygen depletion in bloom waters. The application of organic algal flocculants poses a potential risk of DOM increase in water column, making algal removal become meaningless. However, DOC analysis indicated that the DOC content in algal solution was decreased after algal removal using CS-MS. The DOC was decreased from 3.4 to 3.0, 2.3 and 1.7 mg/L in $CS_{1.0:10}$-MS, $CS_{1.5:10}$-MS and $CS_{2.5:10}$-MS treatments, respectively (**Fig. 3**). The EEM fluorescence spectroscopy (**Fig. 4**) and UV_{254} analysis (**Fig. 3**) indicated that some soluble organic matters could be removed by CS-MS during flocculation-sedimentation process, which contributed to the DOC reduction. Although $CS_{10:0.5}$-MS also exhibited the ability to remove some autochthonous DOM (**Fig. 4** and **Fig. 1**), the high CS loading for the effective algal removal potentially introduced substantial amount of allochthonous organic matters into water column and increased DOC from 3.4 to 3.9 mg/L after algal removal (**Fig. 3**). Thus, in practice, organic flocculants with low charge density are not recommended to be used as soil modifiers in the MS method.

By optimizing the charge density of modifiers, algal cells can be flocculated and settled by MS without increasing DOM in water column. This is necessary although not sufficient for the ecological restoration in eutrophic waters due to the decomposition of the settled organics at surface sediment. Other measures, such as capping treatments using oxygen loaded materials, should be jointly applied after flocculation. Previous studies indicated that nutrient fluxes across sediment-water interface can be reduced or even reversed and surface sediment conditions can be improved by proper capping treatments within a certain period of time (e.g., weeks) (Pan et al., 2012; Pan and Yang, 2012). This may create a window period for the restoration of submerged vegetation. Then, it is possible for the sealed organic matters in the capping layer to be turned into fertilizers for the growth of submerged

vegetation (Pan et al., 2011b; Zhang et al., 2010).

3.3. Co-removal potential of algal cells and DOM

During algal blooms, substantial amount of DOM are often accumulated due to the release and lysis of algal cells, which is an important nutrient pool in eutrophic waters (Nguyen et al., 2005; Ye et al., 2011). The co-removal of algal cells (particulate nutrients) and DOM (dissolved nutrients) may maximize the nutrient reduction and benefit the ecological restoration in eutrophic waters.

During algal flocculation using CS-MS, the decrease in both UV_{254} value (**Fig. 3**) and EEM fluorescence peak intensity (**Fig. 4**) was observed, indicating that CS-MS flocculation has the potential to achieve the co-removal of algal cells and DOM. When CS with the higher charge density was used, more DOM could be removed at the lower optimal CS dosage for algal removal. The UV_{254} was decreased from 0.16 to 0.14, 0.11, 0.10 and 0.08 (**Fig. 3**); and the fluorescence peak intensity at the Ex/Em of 275-280/320-345 nm was decreased from 110.4 to 98.5, 78.5, 73.1 and 33.9 (**Fig. 4**) in $CS_{0.5:10}$-MS, $CS_{1.0:10}$-MS, $CS_{1.5:10}$-MS and $CS_{2.5:10}$-MS treatments, respectively. This suggested that the use of higher charge density CS makes MS not only possess the higher ability of algal removal but also gain a higher ability of DOM removal. Previous studies reported that DOM flocculation is mainly operated by charge neutralization mechanism, which is similar to algal flocculation (Hussain et al., 2013; Lee and Westerhoff, 2006). There may exist competitive binding of algal cells and DOM to MS, and the optimal flocculation of algal cells and DOM may occur at different dosage of CS. Further studies are required to explore the co-removal effect of algal cells and DOM using CS-MS flocculation in bloom waters. Soil particles play an important role in the DOC reduction during CS-MS flocculation. In the soil-only treatment, the DOC and UV_{254} decreased from 3.4 to 2.8 mg/L and from 0.16 to 0.15, respectively (Fig. 3); and the fluorescence peak intensity at the Ex/Em of 275-280/320-345 nm decreased from 110.4 to 80.2 (Fig 4B). However, contaminated soil (by heavy metals and fertilizers etc.) is not recommended to be used. In fields, washing and particle fractionation method can be applied to select large amount of fine soil particles (Li and Pan, 2013).

3.4. Implications for the development of soil modifiers

In the MS method, modifiers make soil particles obtain charge neutralization ability to create algal flocculation potential. Our results demonstrated that the charge density of modifier affects its loading for effective algal removal and thereby DOM content in the treated bloom water. It is necessary to screen flocculants with right charge density to be used as soil modifiers. The charge density can be optimized by regulating the cationic monomer dosage in the production. Confirmation of the optimum one can be determined by jar tests before field applications. Some high charge density materials can be jointly used to facilitate charge neutralization to reduce the loadings of organic modifiers according to the bicomponent modification method (Li and Pan, 2013, 2015b). Besides charge density, the molecular size and structure of modifier chains may affect the bridging function of MS and thereby algal flocculation. Further study is needed to evaluate this effect.

There are various polymers available for the production of cationic flocculants as soil modifiers, such as chitosan, tannin, polysaccharides and polyacrylamides (Yang et al., 2012; Wang et al., 2013a; Wang et al., 2013b). To produce eco-friendly geo-engineering materials, biodegradable natural polymers (e.g., polysaccharides) are preferred, while synthetic polymers (e.g., polyacrylamide) are not recommended to be used, since most synthetic polymer structures are resistant to biodegradation (Bolto and Gregory, 2007). Economic cost is often a main factor limiting large scale application of the method in fields. Cheaply available polymers (e.g., corn starch) should be used to reduce the material costs. Water pH often fluctuates during algal blooms and sometimes even increases as high as 9.5 (Wu et al., 2014). Cationic monomers with quaternary ammonium groups are preferred, since they can not be easily dissociated after grafted onto the polymer backbone as the pH condition changes (Bolto and Gregory, 2007).

4. Conclusions

CS could turn soil particles into effective flocculants for the sedimentation removal of cyanobacterial blooms. The charge density of CS has great influence on DOM content in the treated bloom water. Some soluble organic matters could be removed during

CS-MS flocculation and lead to DOM reduction. However, the use of low charge density CS posed the potential risk of DOM increase in the receiving water due to the high CS loading for effective algal removal. By optimizing the charge density of CS, it is possible to achieve algal removal without increasing DOM content in eutrophic waters.

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