Journal of Hazardous Materials 287 (2015) 7–15

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

To prevent the occurrence of black water agglomerate through delaying decomposition of cyanobacterial bloom biomass by sediment microbial fuel cell

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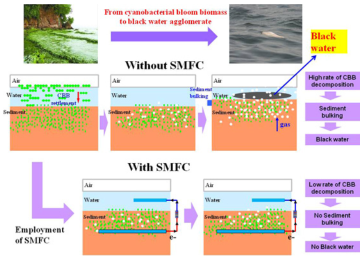
HIGHLIGHTS

- The release of produced gas from CBB decomposition led to sediment bulking.
- Decomposition of settled CBB was delayed with SMFC employment.
- SMFC employment shifted bacterial and archaeal communities in bulk sediments.
- Growth of fermentative *Clostridium* in sediments was inhibited with SMFC.
- SMFC employment prevented sediment bulking and black water agglomerate.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 November 2014
Received in revised form 10 January 2015
Accepted 12 January 2015
Available online 17 January 2015

Keywords:
Black water agglomerate
Cyanobacterial blooms
Lake
Microbial community
Sediment microbial fuel cell

ABSTRACT

Settlement of cyanobacterial bloom biomass (CBB) into sediments in eutrophic lakes often induced the occurrence of black water agglomerate and then water quality deterioration. This study investigated the effect of sediment microbial fuel cell (SMFC) on CBB removal in sediments and related water pollution. Sediment bulking and subsequent black water from decomposition of settled CBB happened without SMFC, but were not observed over 100-day experiments with SMFC employment. While CBB in sediments improved power production from SMFC, the removal efficiency of organic matters in CBB-amended sediments with SMFC was significantly lower than that without SMFC. Pyrosequencing analysis showed higher abundances of the fermentative *Clostridium* and acetoclastic methanogen in CBB-amended bulk sediments without SMFC than with SMFC at the end of experiments. Obviously, SMFC operation changed the microbial community in CBB-amended sediments, and delayed the CBB degradation against sediment bulking. Thus, SMFC could be potentially applied as pollution prevention in CBB-settled and sensitive zones in shallow lakes.

1. Introduction

Due to climate change and anthropogenic carbon and nutrient runoff, cyanobacterial blooms are becoming more common in freshwater lakes and estuaries throughout the world, threatening the sustainability of aquatic ecosystems [1,2]. As cyanobacterial

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http://dx.doi.org/10.1016/j.jhazmat.2015.01.036
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bloom biomass (CBB) dies, it settles on surface sediments, eventually becoming incorporated into sediments through resuspension and bioturbation. In lakes especially shallow lakes, sediment processes dominate the overall metabolic activities [3]. Decaying CBB in sediments has been found to strongly influence the biogeochemical cycling in lakes, and CBB decomposition enhanced sulfate reduction and phosphate release from sediments [4].

Moreover, the accumulation of CBB onto sediments due to wind and water directions, caused unpredictably the occurrence of black water agglomerate [5]. Black water agglomerate in aquatic ecosystems, which is also called "black spot" or "black spot algae", has occurred in many lakes around the world with increased frequency in recent years [6–9]. The occurrence mechanism for black water agglomerate in aquatic environments was not fully known, and might be mainly related to high rates of sulfate-reducing process [8] and the rapid anaerobic decomposition of massive organic matters accumulated into sediments.

As a kind of reactive and labile organic matters, algal biomass was able to be easily decomposed, and thus, prone to lead to black water agglomerate in aquatic environments [10]. On the occurrence of black water agglomerate, the water was highly hypoxic (low oxygen concentration) at the bottom and abruptly becomes black and malodorous. Black water agglomerate was also accompanied by increased chemical oxygen demand and elevated sulfide concentrations [8]. After occurrence, black water agglomerate generally persists several days or even a longer period, and often leads to the death of fish and other aquatic organisms as well as a great threat to drinking water safety. Thus, the pollution of black water agglomerate in lakes needs to be monitored and prevented urgently.

Currently, there existed only limited methods to control this kind of water pollution. Sediment dredging through removing the organic-rich sediments might be one kind of lake restoration techniques to prevent the occurrence of black water agglomerate in lakes [10]. However, dredging is relatively expensive, and dredged sediments must be properly disposed to avoid secondary pollution. Furthermore, dredging might also re-suspend fine sediment particles and liberate trace pollutants to the water column [11]. Alternatively, impeding the quick CBB decomposition and/or diverting the anaerobic metabolism pathways of CBB decomposition might be an effective strategy.

Recently, it was found that the employment of sediment microbial fuel cell (SMFC) was able to decrease the production of adverse and/or harmful compounds from sediments through influencing redox-dependent microbial processes [12]. A SMFC is a type of microbial fuel cell (MFC) with an anode electrode embedded in anaerobic sediments and a cathode electrode suspended in the aerobic water column above the anode electrode [13–15]. Anode-respiring microorganisms in sediments transfer electrons produced during the oxidation of organic or inorganic matters to the anode electrode. Without amending reducing or oxidizing substances into sediments, the employment of only SMFC altered oxidation–reduction potential and pathways of anaerobic metabolism in sediments [14], which led to both the mitigation of methane emission and suppression of sulfate-reducing process [12].

Thus, it seemed reasonable to speculate that SMFC employment could control the occurrence of black water agglomerate from CBB-rich sediments. To test this hypothesis, lab-scale SMFCs were constructed with sediment samples taken from one freshwater lake. Then, CBB was amended to sediments, and SMFCs were operated for over three months. 16S rRNA pyrosequencing was applied to analyze the bacterial and archaeal communities in sediments and on anodes. This study would be helpful in developing new strategies to prevent the pollution of black water agglomerate in aquatic environments.

2. Materials and methods

2.1. Sediment and CBB sampling

Bulk samples of surface sediments were taken manually in June 2012 using a Pedersen grab sampler from the cyanobacterial bloom-occurring zone in Meiliang Bay (31°30′N, 120°11′E) of Taihu Lake, which is a typical eutrophic shallow freshwater lake located in China with an area of 2338 km^2. At the same time, CBB was collected from Meiliang Bay of Taihu Lake. Then, these samples were transported to laboratory within several hours. After sieved at 2 mm, sediment samples were homogenized to reduce heterogeneity within sediments. CBB samples were filtered with a 25 μm filter. Ratios of solid content and solid organic content of CBB samples were $3.01 \pm 0.17\%$ and $92.45 \pm 0.64\%$, respectively.

2.2. Experimental design and SMFC configuration

Sediments with CBB amendment and without any amendment were applied in this study. For each kind of sediments, one treatment was assembled with employment of SMFCs, while the other treatment was operated without SMFC. The ratio of amended CBB to sediments was 0.6% (dry weight/wet weight). After amendment, sediments were agitated for 30 min in dark to get homogeneous mixture. Then, 1 kg of wet sediments was filled in one-litre cylindrical glass beaker with an inner diameter of 11 cm and a height of 15 cm

The lab-scale SMFCs were constructed as described previously in detail [16]. Carbon felt with a thickness of 5 mm was used both as anode (20×7 cm^2) and cathode (7 cm diameter). All electrodes were soaked in 1 M HCl for 24 h and were washed thoroughly with deionized water prior to use. The cathode was fixed 3 cm above the sediment as cathode, while the anode was buried below 3 cm of the sediment surface.

All treatments were operated at 25 °C in dark in a large polymethylmethacrylate box ($60 \times 50 \times 45$ cm) filled with 90 L water to minimize the influence of cathode environment (such as dissolved oxygen and water level) on SMFC operation. Lake water was continuously pumped into the box through a peristaltic pump with a rate of 2 L day^{-1}. The water level in the box was maintained 10 cm above the cathode through setting the position of effluent port. The overlying water was continuously bubbled in the two corners with air to maintain dissolved oxygen concentration above 7 mg L^{-1}. All experiments were conducted in triplicate and operated for 100 days.

2.3. Electrochemical measurements and calculations

Voltage (V) measurements including whole-cell potential and cathode potential were collected with a Keithley model 2700 multimeter (Keithley Instruments 2700, USA) every 30 min. The measured voltage was then converted to a current according to Ohm's law: $V = IR$, and power according to $P = VI$. Electricity current and power density were both calculated based on anodic geometric surface areas (GA). For polarizations behavior test of SMFC, linear sweep voltammetry (LSV) were employed by recording the current at an applied voltage that was lowered in steps of 0.001 V from open-circuit voltage to 0 V with electrochemical workstation (CHI660D, Shanghai Chenhua Device company, China), during which anodes were considered as working electrodes and cathodes as counter electrodes. Based on the polarization curve, power curves describing the power density as a function of current density were obtained.