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Leakage of soluble microbial products from biological activated carbon filtration in drinking water treatment plants and its influence on health risks

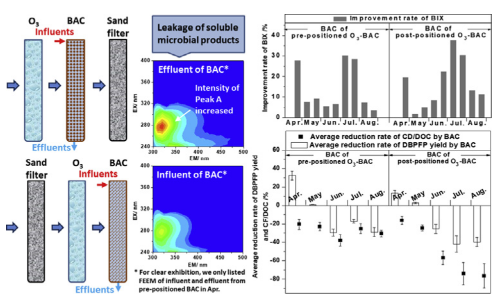
Shen Hong [a], Tang Xian-chun [b], Wu Nan-xiang [a], Chen Hong-bin [b, *]

[a] Institute of Hygiene, Zhejiang Academy of Medical Sciences, Hangzhou, 310007, PR China
[b] State Key Labortory of Pollution Control and Resource Reuse, College of Environmental Science and Engineering, Tongji University, Shanghai, 200092, PR China

HIGHLIGHTS

- SMPs generated by BAC is confirmed by the analyses on FEEM combining with BIX.
- Leakage of SMPs is observed in effluents of both pre- and post-positioned BAC.
- Health risks in increasing DBPFP yield and CF/DOC for SMPs' leakage is suggested.

GRAPHICAL ABSTRACT



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ABSTRACT

The application of ozone-biological activated carbon (O_3-BAC) as an advanced treatment method in drinking water treatment plants (DWTPs) can help to remove organic micropollutants and further decrease the dissolved organic carbon (DOC) level in finished water. With the increase attention to microbial safety of drinking water, a pre-positioned O_3-BAC followed by a sand filter has been implanted into DWTP located in Shanghai, China to increase the biostability of effluents. The results showed that BAC had high removal efficiencies of UV_{254}, DOC and disinfection by-product formation potential (DBPFP). The removal efficiencies between pre- and post-positioned BAC filtrations were similar. Based on the analyses of fluorescence excitation–emission matrix spectrophotometry (FEEM), the generation and leakage of soluble microbial products (SMPs) were found in both two BAC filtrations on account of the increased fluorescence intensities and fluorescence regional integration (FRI) distribution of protein-like organics, as well as the enhanced biological index (BIX). The leakage of SMPs produced by metabolism of microbes during BAC process resulted in increased DBPFP yield and carcinogenic factor per unit of DOC (CF/DOC). Although BAC filtration reduced the DBPFP and CF, there still was high health risk of effluents for the production of SMPs. Therefore, the health risks for SMPs generated by BAC filtration in drinking water advanced treatment process should be addressed, especially with that at high temperature.

* Corresponding author.
E-mail addresses: song.wei0326@163.com (S. Hong), txcchb@126.com (T. Xian-chun), wunanxiang@hotmail.com (W. Nan-xiang), hbctxc@tongji.edu.cn (C. Hong-bin).

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Abbreviation

AC	Activated carbon
BAC	Biological activated carbon
BDCM	Bromodichloromethane
BFM	Bromoform
BIX	Biological index
CDBM	Dibromochloromethane
CF	Carcinogenic factor
CFM	Chloroform
DBAA	Dibromoacetic acid
DBPFP	Disinfection by-product formation potential
DBPs	Disinfection by-products
DCAA	Dichloroacetic acid
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DWTP	Drinking water treatment plant
EBCT	Empty bed contact time
FEEM	Fluorescence excitation–emission matrix spectrophotometry
FRI	Fluorescence regional integration
HAAs	Haloacetic acids
HAAFP	Haloacetic acid formation potential
HIX	Humification index
MCAA	Chloroacetic acid
MBAA	Bromoacetic acid
MW	Molecular weight
OTUs	Operational taxonomic units
O_3-BAC	Ozone-biological activated carbon
PCR	Polymerase chain reaction
QIIME	Quantitative insights into microbial ecology
SMPs	Soluble microbial products
SMPs-BAP	Biomass associated SMPs
SMPs-UAP	Utilization associated SMPs
SUVA	Specific UV absorbance
TCAA	Trichloroacetic acid
THMs	Trihalomethanes
THMFP	Trihalomethanes formation potential
UV–Vis	Ultraviolet–visible
UV_{254}	UV–Vis spectrophotometer with 254 nm
UV_{280}	UV–Vis spectrophotometer with 280 nm

1. Introduction

For the increasing concentration of dissolved organic matter (DOM) in source water and disinfection by-products (DBPs) generated by chlorination, the ozonation integrated with biological activated carbon (BAC) filtration has been extensively used as an essential step in advanced treatment of drinking water (Delpla and Rodriguez, 2016; Korotta-Gamage and Sathasivan, 2017). The health risks due to the leakage of microorganisms (e.g., bacteria and invertebrates) in effluents during the biodegradation process in BAC filtration have caused wide public concern (Li et al., 2017; Liao et al., 2018; Zhang et al., 2017a). In order to increase the biostability of drinking water, it is important to reduce the microbial contamination in effluents, especially with high temperatures (Lu et al., 2014; Sarker et al., 2013). Thus, an advanced treatment process equipped with pre-positioned O_3-BAC process followed by a sand filter had been introduced to determine the invertebrates leaked from BAC column (Zhu et al., 2014).

Continued research about the generation of both carbon- and nitrogen-based DBPs from DOM in drinking water treatment plants has gradually revealed the key role of soluble microbial products (SMPs), which was found to be a product of microorganisms' metabolism from BAC filtration (Chu et al., 2015; Wang et al., 2017; Zhang et al., 2015). Most of previous studies have only concerned SMPs from the wastewater biotreatment process or the bio-pollutants leakage into drinking water sources (Holakoo et al., 2006; Liu and Li, 2010). Recently, increasing studies began to address the SMPs produced during drinking water treatment processes (Liu et al., 2017; Zhang et al., 2017b; Shen et al., 2016).

The ultraviolet–visible (UV–Vis) absorption spectroscopy has been applied widely to detect the DOM in solutions. Because the average absorptivity at 254 nm of organic molecules, the specific UV absorbance ($SUVA_{254}$) has become extensively used for characterization of DOM and prediction of DBPs in drinking water. However, for the differences in UV characteristics of DOM in various water samples, there were still limitations according to the different relationships between $SUVA_{254}$ and DBPs of different water sources (Ates et al., 2007).

Based on the fluorescence signals of excitation and emission for each sample, FEEM provided a lot of details about DOM in both wastewater and drinking water treatment processes (Cai et al., 2016; Hudson et al., 2007). Fluorescence indices, including the humification index (HIX) and the biological index (BIX), were originally used to characterize the sources or properties of DOM in soil and natural water (Huguet et al., 2009). With the introduction and use of FEEM spectrophotometry in environmental monitoring, fluorescence indices have been widely applied during water treatment process (Cai et al., 2017; Ramón et al., 2016).

Considering the key role of BAC on SMPs production, two BAC filtrations of O_3-BAC processes with different operation sequence in the same drinking water treatment plant (DWTP) were selected as the research objects. The purposes of this paper were: (i) by using FEEM spectrophotometry, scanning electron microscopy (SEM), and quantitative insights into microbial ecology (QIIME) to analyze the removal efficiency of DOM by two BAC filtrations of O_3-BAC processes with different operation sequence, (ii) to introduce fluorescence indices (such as BIX and HIX) and FRI method to explore the variations on spectral characteristics of DOM, as well as the formation and leakage of SMPs, (iii) to discuss the health risks based on the removal efficiencies of DBPFP yield and carcinogenic factor per unit of DOC (CF/DOC) by BAC filtration.

2. Materials and methods

2.1. Drinking water treatment plant layout and operation

Water samples of the influents and effluents of two BAC filtrations (sample A, B, C and D shown in Fig. 1) were collected from a DWTP that supplies water to Shanghai, China. Daily water supply of the DWTP is about 900 $km^{3*}d^{-1}$, which accounts for about 9% of Shanghai's total supply. The source water for this plant is diverted from the Huangpu River. In this DWTP, two kinds of advanced treatment system equipped with O_3-BAC are used, parallelly (Fig. 1); one is an O_3-BAC/sand filtration process with a purifying capacity of 600 $km^{3*}d^{-1}$ in which the O_3-BAC precedes the sand filter (pre-positioned O_3-BAC), and the other is a sand filtration/O_3-BAC process with a purifying capacity of 300 $km^{3*}d^{-1}$ in which the O_3-BAC is placed after the sand filter (post-positioned O_3-BAC). The characteristics of BAC are shown in Table S1, and the typical characteristics of the influents and effluents of BAC filtration during the