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Characteristics of molecular weight distribution of dissolved organic matter in bromide-containing water and disinfection by-product formation properties during treatment processes

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ABSTRACT

The characteristics of dissolved organic matter (DOM) and bromide ion concentration have a significant influence on the formation of disinfection by-products (DBPs). In order to identify the main DBP precursors, DOM was divided into five fractions based on molecular weight (MW), trihalomethane formation potential (THMFP) and haloacetic acid formation potential (HAAFP) were determined for fractions, and the change in contents of different fractions and total DBPs during water treatment processes (pre-chlorination, coagulation, sand filtration, disinfection) were studied. Moreover, the relationship between bromide concentration and DBP generation characteristics in processes was also analyzed. The results showed that the main DBP precursors were the fraction with MW < 1 kDa and fraction with MW 3–10 kDa, and the DBP's generation ability of lower molecular weight DOM (<10 kDa) was higher than that of higher molecular weight DOM. During the different processes, pre-chlorination and disinfection had limited effect on removing organics but could alter the MW distribution, and coagulation and filtration could effectively remove organics with higher MW. For DBPs, trihalomethanes (THMs) were mainly generated in pre-chlorination and disinfection, while haloacetic acids (HAAs) were mostly generated during pre-chlorination; coagulation and sand filtration had little effect on THMs but resulted in a slight removal of HAAs. In addition, the results of ANOVA tests suggested that molecular sizes and treatment processes have significant influence on DBP formation. Moreover, with increasing bromide concentration, the brominated DBPs significantly increased, but the bromine incorporation factor in the processes was basically consistent at each concentration.

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Introduction

Disinfection by-products (DBPs) in drinking water formed during chlorination and chloramination processes have drawn worldwide attention. Among the DBPs, trihalomethanes (THMs) and haloacetic acids (HAAs) are the most representative substances (Agbaba et al., 2016; Ding et al., 2013; Krasner et al., 1989; Richardson and Postigo, 2012; Wang and Zhu, 2010), and many toxicological and biological experiments have indicated that THMs and HAAs could be potentially hazardous to humans

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and may lead to carcinogenesis, teratogenesis and mutagenesis (Andrews et al., 2004; Hsu et al., 2001; Mash et al., 2014; Rodriguez et al., 2000). Researchers have proved that dissolved organic matters (DOMs) were the primary precursors of DBPs, as they could easily react with free chlorine to generate THMs and HAAs (Han et al., 2015; Krasner et al., 1989; Yang et al., 2015; Zeng and Arnold, 2014; Zheng et al., 2016), and some studies have also investigated the formation characteristics of different DOM fractions with different molecular size, hydrophilicity and so on (Hua and Reckhow, 2007; Hur et al., 2013; Imai et al., 2003; Lin et al., 2015; Niu et al., 2015b; Panyapinyopol et al., 2005). DOM fractions with different molecular weight (MW) showed markedly different physical and chemical properties during water treatment processes, which can make the kinds and amounts of halogenated DBPs remarkably diverse (Collins et al., 1986; Han et al., 2013). Therefore, classifying DOM into different fractions by MW and investigating their variation trends during water treatment processes are important to controlling halogenated DBPs. What's more, brominated DBPs have been of wide concern in recent years, and many studies have been carried out to determine their generation characteristics (Chowdhury et al., 2016; Zha et al., 2014, 2016; H. Zhang et al. 2015).

Several studies have reported the effect of the molecular weight of organic matter on DBP formation potential. For example, two source waters from South Carolina and New York were studied comparatively, and the results showed that the production of DBPs increased with the increase of MW in the former water, but the major precursors were fractions with MW < 3 kDa in the latter, indicating that the formation characteristics of DBPs of different MW components differed in different water bodies, and the MW distribution of natural waters had a strong regionalism (Kitis et al., 2002; Lin et al., 2007). Water from the Pearl River was fractioned into different groups based on MW, and it was discovered that the fraction with MW < 0.5 kDa was the main organic component of DOM (at 58%), and that the components with different MW exhibited marked differences in reacting with chlorine (Zhao et al., 2006). A study focused on the reaction characteristics of humic acids in disinfection process was conducted, and observed that the main precursors were the smaller molecule matters (Zhang et al., 2005). Detailed analysis of THMs showed that chloroform (TCM) was mainly produced by the fraction with MW of 0.5–10 kDa, while dibromochloromethane (DBCM) and tribromethane (TBM) were mainly generated from the fraction with MW < 0.5 kDa (Chang et al., 2000).

Moreover, in studies focusing on the decrease of DOM it was determined that conventional water treatment technologies, including coagulation processes, filtration processes and disinfection processes, demonstrated clear discrepancies in removal capability for components with different MW (Collins et al., 1986; Han et al., 2013; Wang and Liu, 1999). Experiments showed that the conventional coagulation process mainly removed organic matters whose molecular weights were more than 10 kDa, and pre-oxidation and pre-adsorption processes could effectively improve the removal rate of organics (Han et al., 2013). The slow sand filtration process could remove most DOMs with higher molecular size from river water, and the subsequent photo-Fenton process could strengthen the removal efficiency (Moncayo-Lasso et al., 2008). During disinfection, researchers found that DOM fractions with MW < 2.5 kDa would be decreased more than other fractions, and produce higher concentrations of DBPs (Kristiana et al., 2013).

The influence of the bromide ion on the speciation and yield of THMs and HAAs in chlorination and other processes was also investigated, and it was found that the brominated DBP (Br-DBP) concentration increased with increasing bromide concentration (Hua et al., 2006; Zha et al., 2014). Experiments showed that with increasing bromide concentration, the total yields of THMs and HAAs increased (Bond et al., 2014); six bromide concentrations ranging from 0.05 to 4.0 mg/L were studied during chlorination, and the results showed that the speciation of THMs and HAAs gradually shifted from chlorinated species to mixed bromochloro species during chlorination with the increase of bromide concentration (Uyak and Toroz, 2007).

To date, the primary precursors of DBPs have been determined to be different in different water bodies (Chang et al., 2000, 2001; Zhang and Minear, 2002), and the ability of organic fractions to generate DBPs is also different (Zhao et al., 2013). Meanwhile, few studies simultaneously considered the relationship between fractions with different MW and the contents of DBPs in water treatment processes, and fewer integrated the effects of bromide ion.

The purpose of this study is to analyze the organic fractions with different MW in Yuqiao Reservoir, study the disinfection by-product formation potential (DBPFP) (including trihalomethane formation potential (THMFP) and haloacetic acid formation potential (HAAFP)) of the source water, and also analyze the change characteristics of organic fractions and contents of DBPs during sequential water treatment processes. In consideration of the bromide ion pollution in the source water, we enhanced the bromide concentration and set several levels to study the relationship between bromide ion concentration and DBP generation characteristics in treatment processes. Through this work, we hope to identify the primary precursors of THMs and HAAs of Yuqiao Reservoir, to provide information on the change characteristics of organic fractions with different molecular size, the relationship between bromide and DBP generation characteristics in treatment processes, and finally, to provide suggestions for the control of DBPs in water treatment processes.

1. Materials and methods

1.1. Sample collection

All samples were collected from Yuqiao Reservoir located in Tianjin, North China. Yuqiao Reservoir is the most important water resource for Tianjin in North China, with a capacity of 1.559 billion m^3, supplying drinking water for 15.17 million people in Tianjin (H. Zhang et al., 2015; Y. Zhang et al., 2015). The water quality of Yuqiao Reservoir has a strong impact on the drinking water quality of Tianjin. In recent years, researchers have conducted various studies on the water quality of Yuqiao Reservoir. For example, the dynamic change of chlorophyll (Liu et al., 2014), correlation analysis of the richness of phytoplankton and the main water factors (Zhang et al., 2013), the heavy metals in the surface sediment (Wu et al., 2011), and eutrophication forecasting and management

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