WATER RESEARCH 42 (2008) 2135–2145

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Biostability and disinfectant by-product formation in drinking water blended with UF-treated filter backwash water

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ARTICLE INFO

Article history:
Received 21 August 2007
Received in revised form
18 November 2007
Accepted 19 November 2007
Available online 24 November 2007

Keywords:
Filter backwash water
Ultrafiltration
Biostability
Disinfectant by-products

ABSTRACT

The overall objective of this study was to investigate the impact of blending membrane-treated water treatment plant (WTP) residuals with plant-filtered water on finished water quality in terms of biostability and disinfectant by-product (DBP) formation. Filter backwash water (FBWW) was treated with a pilot-scale ultrafiltration (UF) membrane to produce permeate that was blended with plant-finished water. The batch studies involved storing samples for a specified time with a disinfectant residual to simulate residence time in the distribution system. Both chlorinated and non-chlorinated FBWW streams were evaluated, and the experimental design incorporated free chlorine, monochloramine, and chlorine dioxide in parallel to a model system that did not receive a disinfectant dose. The results of the study found that blending 10% UF-treated FBWW with plant-filtered water did not have an impact on water biostability as monitored with heterotrophic plate counts (HPCs) or DBP concentrations as monitored by TTHM and HAA5 concentrations. However, the presence of preformed THM and HAA species found in chlorinated FBWW streams may result in higher levels of initial DBP concentrations in blended water matrices, and could have a significant impact on finished water quality in terms of meeting specific DBP guidelines or regulations.

1. Introduction

Chemical disinfection in drinking water treatment has been shown to result in substitution reactions between chlorine and natural organic matter (NOM) to form halogenated organic compounds that are referred to as disinfection by-products (DBPs) (Rook, 1974; Bellar et al., 1974). The two most prevalent classes of chlorinated DBPs that have received increased attention over the past 25 years are trihalomethanes (THMs) and haloacetic acids (HAAs) due to the identification of potential adverse health effects from exposure to these compounds (e.g., increased incidence of cancer and adverse human reproductive outcomes) (Bull and Kopfler, 1991; Bull et al., 2001; Dodds et al., 2004). In the United States, Stage 1 of the Disinfectants-Disinfection By-Products Rule (D/DBP Rule) has established maximum contaminant levels (MCLs) of 80 μg/L for total trihalomethanes (TTHMs) and 60 μg/L for five species of the HAA group (HAA5) (US EPA, 1998). In Canada, the Federal–Provincial–Territorial Committee on drinking water quality has an established maximum acceptable concentration (MAC) for TTHMs of 100 μg/L and is in the process of developing guidelines for

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0043-1354/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2007.11.024

HAA (Health Canada, 2006). The European Union has no limit value for HAAs, but has a maximum contaminant level of 100 μg/L for the four THMs (Council Directive 98/83/EC, 1998).

There are two main approaches that water utilities have taken to achieve regulatory compliance for DBP concentrations in the distribution system. The first approach involves redesign of disinfection strategies by moving the point of disinfection and/or switching to alternative chlorine-based disinfectants. Numerous studies have demonstrated that changing from chlorine to chloramines or chlorine dioxide (ClO_2) disinfectants results in lower concentrations of THMs and HAAs (Fleischacker and Randtke, 1983; Stevens et al., 1989; Gordon, 1992; Richardson et al., 1994, 2002; Carlson and Hardy, 1998; Diehl et al., 2000; Volk et al., 2002). The second approach involves optimization of the main treatment train to achieve higher removal targets of DBP precursors (e.g., organic material). The latter approach is also important for managing microbiological growth, as dissolved organic carbon (DOC) represents a significant nutrient source in distribution systems.

For utilities that recycle water treatment plant (WTP) waste residual streams such as filter backwash water (FBWW) within the main treatment train, there exists the potential to upset compliance with DBP regulations or guidelines in the distribution system. The use of chlorinated finished water to backwash filters has been shown to result in THM and HAA concentrations that are 24- to 92-fold higher in FBWW streams (Arora et al., 2001). As suggested by Cornwell and Lee (1993), preformed THM is generally recycled along with FBWW and the effect that this may have on a plant meeting THM requirements needs to be evaluated on a site-specific basis. In addition, WTP residuals are characterized as being highly concentrated in organic material in both the particulate and dissolved fractions (Arora et al., 2001; Cornwell et al., 2001; Edzwald et al., 2001). While previous studies have demonstrated that recycle design does not negatively impact the removal of particulate matter in the main treatment train (Cornwell and Lee, 1993; Cornwell et al., 2001; Edzwald et al., 2001), it is recognized that possible increased passage of DOC through the main processing units could potentially impact DBP formation and biostability in the distribution system under certain disinfection strategies.

The growing familiarity with membrane technology coupled with high organic and microbial loadings within FBWW presents an ideal application for membrane separation technology within residuals management designs (Arora et al., 2001). For this reason, the use of low-pressure membranes such as microfiltration (MF) or ultrafiltration (UF) for the treatment of WTP residual streams has been investigated at the bench, pilot and full scale (Thompson et al., 1995; Taylor et al., 2000; Shealy et al., 2000; Cornwell et al., 2001; Brugger et al., 2001; MacPhee et al., 2002; Bourgeois et al., 2004; LeGouellec et al., 2004). Those studies have focused on evaluating the capabilities of MF and UF systems to remove pathogens and other particulate contaminants present in FBWW streams, but have provided limited data related to the potential accumulation of DOC and/or DBPs within the distribution system.

The purpose of this study was to investigate the potential impacts of blending UF-treated residual streams with plant-finished water on distribution system water quality in terms of DBP formation and water biostability. In the United States, plants that practice residuals recycle are required to return these flows through the processes of a system's existing conventional or direct filtration systems (US EPA, 2001). However, due to the improved contaminant removal capabilities of UF technology, the current study evaluated the feasibility of blending UF-treated residual streams upstream of a drinking water plant's clearwell. A series of bench-scale experiments was conducted by storing samples for 25 days with an initial disinfectant residual to simulate residence time in a distribution system. Both chlorinated and non-chlorinated FBWW streams were evaluated. Both sets of experiments investigated free chlorine, monochloramine and ClO_2 disinfection in terms of potential impacts to THM and HAA formation and biostability under residuals recycle design.

2. Materials and methods

2.1. Source water

Two surface source waters were chosen for this investigation, specifically the Lake Major WTP in Dartmouth, Nova Scotia, Canada, and the R.C. Harris WTP in Toronto, Ontario, Canada. The Lake Major WTP is a 45-MLD plant that serves the surrounding areas of Dartmouth, Nova Scotia, Canada. The R.C. Harris plant draws water from Lake Ontario and is the largest water treatment facility in Toronto, Ontario, with a designed plant capacity of 910 MLD. Both facilities are conventional surface water filtration treatment trains, with coagulation, flocculation, sedimentation and dual-media filtration. The primary difference between the two plants besides production capacity is disinfection design. The R.C. Harris plant seasonally uses chlorine at the intake of the plant for zebra mussel control, and continuously applies ammonia to the finished water to convert free chlorine to chloramines for microbiological control within the distribution system. At the time of sampling for this project, the chlorine at the intake of the plant was not being added. The Lake Major plant uses free chlorine before the filters for enhanced manganese removal and applies chlorine in the finished water to maintain a free chlorine residual of 0.2 mg/L in the distribution system. Therefore, FBWW samples from the Lake Major WTP were representative of a chlorinated FBWW waste stream, while samples taken from the R.C. Harris facility were representative of a non-chlorinated FBWW waste stream.

2.2. Bench- and pilot-scale test equipment

The pilot-scale membrane testing system consisted of a UF membrane module (ZeeWeed-10, ZENON Environmental Ltd., Burlington, Ontario) with a 0.1 μm absolute pore size and a 0.04 μm nominal pore size. The ZW-10 module utilizes a ZeeWeed™ 500 hollow-fiber membrane and operates in an immersed, outside-in configuration. For these experiments, the UF membrane was operated in a dead-end filtration configuration at a constant flux rate of 32.3 L/m^2 h. The ZW-10