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Disinfection by-products in filter backwash water: Implications to water quality in recycle designs

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ABSTRACT

The overall purpose of this research was to investigate disinfection by-product (DBP) concentrations and formation potential in filter backwash water (FBWW) and evaluate at bench-scale the potential impact of untreated FBWW recycle on water quality in conventional drinking water treatment. Two chlorinated organic compound groups of DBPs currently regulated in North America were evaluated, specifically trihalomethanes (THMs) and haloacetic acids (HAAs). FBWW samples were collected from four conventional filtration water treatment plants (WTP) in Nova Scotia, Canada, in three separate sampling and plant audit campaigns. THM and HAA formation potential tests demonstrated that the particulate organic material contained within FBWW is available for reaction with chlorine to form DBPs. The results of the study found higher concentrations of TTHMs and HAA9s in FBWW samples from two of the plants that target a higher free chlorine residual in the wash water used to clean the filters (e.g., clearwell) compared to the other two plants that target a lower clear well free chlorine residual concentration. Bench-scale experiments showed that FBWW storage time and conditions can impact TTHM concentrations in these waste streams, suggesting that optimization opportunities exist to reduce TTHM concentrations in FBWW recycle streams prior to blending with raw water. However, mass balance calculations demonstrated that FBWW recycle practice by blending 10% untreated FBWW with raw water prior to coagulation did not impact DBP concentrations introduced to the rapid mix stage of a plant's treatment train.

1. Introduction

Conventional drinking water treatment trains have a filtration process which is considered a polishing step. Many modifications and additions have been made to water treatment processes, but filtration remains one of the fundamental technologies (Baruth, 2005). Over a filtration cycle in granular media filtration units, the filters become loaded with particles, organic material and bacteria. To maintain performance and treatment efficacy, backwashing with water is conducted to periodically remove contaminant material that is captured in the filtration units. For individual plants, backwash cycles are scheduled anywhere from 1 to 7 days, depending on raw water quality and main treatment train design and operations (e.g., conventional versus direct filtration, coagulant dose).

Waste filter backwash water (FBWW) is the largest primary liquid waste residual volume generated in a conventional or direct filtration plant. It is estimated that 3–10% of a plant's total water production is consumed by this process (AWWA 1999). FBWW streams from surface water plants have been shown to be highly concentrated in total suspended solids (TSS), turbidity, and inorganics such as aluminum and/or iron that reflect

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naturally occurring contaminants in the raw water as well as precipitates from the inorganic coagulants used during treatment (Cornwell et al., 2001; Edzwald et al., 2001; Arora et al., 2001; Bourgeois et al., 2004; Walsh and Gagnon, 2006; Walsh et al., 2008). The concentrated organic content of FBWW streams has been shown to be primarily in the particulate size fraction (i.e., >0.45 μm), with total organic carbon (TOC) concentrations consistently found to be significantly higher than DOC concentrations in several studies (Arora et al., 2001; Cornwell et al., 2001; Edzwald et al., 2001; Gottfried et al., 2008). Most FBWW streams from drinking water treatment plants will contain many of the above constituents, but the quality of FBWW will vary from plant to plant due to the differences in raw water quality and differences in treatment train design.

Chlorine is the most commonly used disinfectant in North America. Chlorine reacts with biogenic organic matter, such as humic and fulvic acids which are present in all natural surface waters (Health Canada, 1996), and the substitution reactions that occur form halogenated organic compounds referred to as disinfection by-products (DBPs) (Rook, 1974; Bellar et al., 1974). Over the past 25 years, two prevalent classes of DBPs, trihalomethanes (THMs) and haloacetic acids (HAAs) have been reported due to the identification of potential adverse health risks, such as 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 haloacetic acids group (HAA5) (U.S. EPA, 1998), based on running annual averages of plant quarterly samples. The recent promulgation of the Stage 2 Disinfectants and Disinfection Byproducts Rule by the U.S. Environmental Protection Agency (U.S. EPA, 2006) builds on existing regulations by requiring water systems to comply with the MCLs for TTHM and HAA5 at specific monitoring sites in the distribution system, with monitoring frequency established by the size of the system. 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 80 μg/L for HAA5 (Health Canada, 2009). 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).

Results of water quality analysis conducted on waste FBWW samples collected from 25 water systems over a one year period showed TTHM concentrations ranged from non-detect (ND) to 198 μg/L and HAA6 concentrations ranged from ND to 211 μg/L (Cornwell et al., 2001). As highlighted in that study, elevated DBP concentrations in waste FBWW samples may be attributed to the use of chlorinated finished water for the purpose of filter backwashing. Chlorinated water from a plant's clearwell is often used to backwash filters in drinking water treatment, although the exact contribution of the NOM trapped within filters and reactions with chlorinated wash water is complex and not well documented in literature. Work conducted by Edzwald et al. (2001) in this area examined the contribution to DBP formation of particulate versus adsorbed organic carbon contained within a filter related to differences in treatment train design (e.g., direct versus conventional filtration). The results of that study determined that filter associated organic carbon contributes to DBP formation in waste FBWW streams.

Other work has demonstrated that the type of disinfectant used in the main treatment train can impact THM and HAA concentrations in waste FBWW. A study by Walsh et al. (2008) found that waste FBWW from a conventional filtration plant that uses chloramines for disinfection had TTHM and HAA5 concentrations that were 76 and 96% lower, respectively, than those measured in waste FBWW samples from another conventional filtration plant that uses chlorine for disinfection. However, the exact contribution of chlorinated wash water on DBP formation in waste FBWW was not identified as part of that study, as the plant employing chlorine for disinfection also has a chlorine injection before filtration for manganese removal.

The overall objective of this study was to investigate TTHM and HAA9 concentrations and formation potential in FBWW sampled from four different conventional filtration plant designs. For the purposes of this study, FBWW is defined as waste filter backwash water generated in dual-media filters that is not treated prior to recycle (e.g., no solid separation). Because DBPs are of potential concern when recycling FBWW streams within a water treatment plant, surrogate water quality parameters that can be easily measured in FBWW samples were evaluated as to the capability to present predictive tools for DBP concentrations in FBWW streams. In addition, as the formation of DBPs has been shown to be a function of chlorine dose, pH, temperature and contact time (Health Canada, 1996), this study also evaluated, at bench-scale, TTHM and HAA9 concentrations in the FBWW samples under different storage conditions.

2. Materials and methods

2.1. Source waters and WTP descriptions

Raw source and FBWW samples were obtained from four surface water treatment plants in Nova Scotia, Canada, at three different sampling times throughout the year. Representative FBWW samples from all of the plants were obtained by evaluating backwash flow rates and selecting sample times and volumes that would provide a composite sample of the entire volume over the period of one complete backwash cycle. The FBWW samples were obtained directly from the overflow catchments of the filters during the backwash cycle.

A summary of the process design of the four WTPs in Windsor, Bridgewater, Truro and New Glasgow, N.S. is presented in Table 1. All four plants are conventional treatment trains with either sedimentation (SED) or dissolved air flotation (DAF) clarification followed by dual-media filters comprised of anthracite and sand. All four plants use aluminum sulphate (alum) as the primary coagulant. Two of the plants studied have chlorine injection upstream of filtration for oxidation of iron and manganese. The New Glasgow WTP adds chlorine at a dose of 0.4 mg/L at the raw water intake to the plant, and the Truro WTP adds chlorine at a dose of 1.2 mg/L to the clarified water before filtration. All of the four plants in this study add chlorine to the clearwell for disinfection and the chlorinated water from the clearwell is used to backwash the filters.