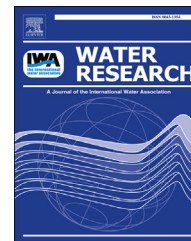


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Disparity in disinfection byproducts concentration between hot and cold tap water



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ABSTRACT

The quality of water entering a distribution system may differ substantially from the quality at the point of exposure to the consumer. This study investigated temporal variations in the levels of regulated and non-regulated disinfection byproducts (DBPs) in cold and hot tap water in a home on a medium-sized municipal water system. In addition, samples were collected directly from the water plant with some being held in accordance with a simulated distribution system (SDS) test protocol. The location for this work was a system in western Massachusetts, USA that uses free chlorine as a final disinfectant. Very little short term variability of DBPs at the point of entry (POE) was observed. The concentration of DBPs in the time-variable SDS test was similar to concentrations in the cold water tap. For most DBPs, the concentrations continued to increase as the cold water tap sample was held for the time-variable SDS incubation period. However, the impact of heating on DBP levels was compound specific. For example, the concentrations of trihalomethanes (THMs), dichloroacetic acid (DCAA) and chloropicrin (CP) were substantially higher in the hot water tap than in the cold water time-variable SDS samples. In contrast, the concentration of trichloroacetic acid (TCAA) was lower in the heated hot tap water, but about equal to that observed in the cold tap water. The situation was more pronounced for dichloroacetonitrile (DCAN), bromodichloroacetic acid (BDCAA), bromochloroacetic acid (BCAA) and 1,1,1-trichloropropanone (TCP), which all showed lower concentrations in the hot water than in either of the cold water samples (instantaneous or time-variable SDS). The latter was viewed as a clear indication of thermally-induced decomposition. The ratio of unknown total organic halide (UTOX) to TOX was substantially lower in the hot tap water as the THM to TOX ratio became correspondingly larger. The results of this study show that DBP exposure in the home is not well represented by concentrations measured in cold water taps where most compliance monitoring is done.

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1. Introduction

Disinfection byproducts (DBPs) are a concern in municipal water systems because of their potential health risks and

because of current federal and state regulations limiting their concentrations. Assessing human exposure to DBPs is a challenging task because of their high degree of temporal and spatial variability and the multiple routes of exposure. In addition to ingestion of cold tap water, inhalation and

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dermal absorption are likely to be important exposure pathways (Maxwell et al., 1991; King et al., 2004; Whitaker et al., 2003; Nuckols et al., 2005). For example, hot water use was found to have an important impact on people's exposure to trihalomethanes (THMs) (Gordon et al., 1998; Nuckols et al., 2005; Miller et al., 2002).

Many studies of hot water exposure have focused on the relationship of hot water DBP concentrations and concentrations in the exposed individual's breath and blood (Nuckols et al., 2005). For research applied to exposure through ingestion, the temperatures selected were either at the boiling point (Betterman et al., 2000; Wu et al., 2001; Krasner et al., 1989) or seasonally elevated temperature (i.e., <40 °C; Arora et al., 1997). In these studies, the elevated temperatures were held constant throughout the incubation period (e.g. Zhang et al., 2013). However, none of published studies were designed to examine DBP profiles in domestic hot water systems, where temperatures become elevated midway through the reaction of chlorination with NOM (natural organic matter).

Very little research has been conducted on the temporal variability of disinfection byproduct concentrations in household plumbing systems especially when including the impact of water heaters. Dion-Fortier et al. (2009) studied the effect of electric water heaters and plumbing on THM and HAA levels. They observed considerable increases in THMs when water stagnated in pipes and hot water tanks, and they noted that HAAs increased as well but less significantly. Yamamoto et al. (2007) evaluated the effect of storage time in building plumbing systems on the variation of trihalomethane levels. They found the total THM levels to be higher in building plumbing systems than the city water entering the home, and additional incubation of the city samples produced levels that approached the levels of THMs in the building stored water. While they did not explicitly examine the effect of heating; they did report that the average daily air temperature was positively correlated with the total THM level. Eyring et al., 2008 collected hot and cold water samples throughout the Philadelphia system in 2006. Philadelphia uses chloramines as a final disinfectant with average residuals of about 1.5 mg/L across the system, and average treated DOC levels of about 1.5 mg/L as well. THM levels in hot tap water were found to be about double the amount in cold tap water. However, hot water HAA levels were found not to differ as much from the corresponding cold water values. Li and Sun (2001) investigated the enhanced formation and volatilization of trihalomethanes in water heaters. However, their experimental design (quickly heating to the boiling point with large air spaces) may not have been appropriate to home water heaters.

Home processing of potable water (boiled, filtered, refrigerated) is very common in the US, which may serve to reduce exposure to DBPs by ingestion. As a result, exposure to DBPs during hot water use activities (showering, bathing) may become more significant. In order to improve the accuracy of DBP exposure assessments, the concentrations of DBPs in water coming from home water heaters needs to further study. In a companion paper (Liu and Reckhow, 2013) the concentrations of DBPs under simulated water heating conditions were found to exhibit substantially different behavior compared to non-heated water, and these differences

changed with increasing distribution system water age. In the current study, we document the detailed temporal variation of DBPs at cold and hot tap water from an actual water heater at a single-family home.

2. Experimental methods

2.1. Distribution system background

One average-sized single-family residence in the City of Northampton, MA was selected for this study. This house used a 60 gallon conventional water tank for heating up the water. The tap water of the residential property selected for this study was supplied by the City of Northampton's Department of Public Works-Water division through 36 inch ductile iron and 20 inch cast iron transmission mains which branch off to smaller diameter residential piping. The Northampton water treatment plant, with a design flow of 6.5 million gallons per day (MGD), delivers 2.9 MGD on an average day to its 28,000 customers. Approximately 90% of Northampton's drinking water comes from three surface water reservoirs: the Francis P. Ryan, and the West Whately Reservoirs, located in the town of Whately, and the Mountain Street Reservoir located in Williamsburg and Hatfield. The remaining 10% comes from its two groundwater wells in Florence. Since 2008, the operation of its water filtration plant, which is comprised of an upflow roughing filter (adsorption clarifier) and a granular activated carbon filter, has significantly reduced the amount of total organic carbon and DBPs in the system. As a result, the city's DBP levels are well below the maximum contaminant levels (MCLs) set by the Stage 2 Disinfectants/Disinfection Byproducts (D/DBP) Rule. Sodium hypochlorite (1.5–1.7 mg/L) is added to the filtered water prior to entering a 4 million gallon storage tank. As the water leaves the 4 million gallon storage tank, sodium carbonate is added for pH adjustment and corrosion control. Zinc orthophosphate is added as a corrosion inhibitor.

2.2. Experimental design

Water samples were collected from the entry point of the system (POE) at the effluent of the Northampton water treatment facility and at a residential distribution location over a 40 h period. The total transit time from the POE to the residential sampling site was about 18–30 h based on the flow conditions as impacted by the community water use during the sampling period. At the POE, bulk effluent samples were collected at 3 pm on Monday afternoon and were incubated in a temperature-controlled water bath in the lab at the actual system temperature (7–8 °C) to simulate the DBP formation profile expected during transit from the POE to the residential sampling site (i.e., the “SDS” tests). The incubated samples were analyzed for DBPs starting at 6:30 pm on Monday and analysis continued over a 40 h period.

The effect of varying plant effluent quality was determined by monitoring the instantaneous DBP levels in POE samples. In addition, the levels of DBPs in unquenched POE water samples (i.e., terminal) were measured after holding the samples for 28 days at 4 °C. These are intended to represent

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