Trihalomethane Formation Potential in Rainwater Harvested from Different Roofing Materials

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Abstract

Rainwater harvesting systems are one way to address the worldwide increase in water demand. If the harvested rainwater is for indoor use, residential users often disinfect it. If it is disinfected with chlorine, the presence of dissolved organic carbon (DOC) can lead to the formation of

harmful disinfection by-products such as trihalomethanes (THMs). Although the quality of harvested rainwater produced in individual residences is not regulated, it would be wise for a user to comply with United States Environmental Protection Agency drinking water standards; total THMs are regulated at 80 μg/L in tap water. In this study, we examined THM formation in chlorinated rainwater harvested from a full-scale asphalt fiberglass shingle roof. Under disinfection conditions relevant for a residence, total THMs were formed at concentrations from 28 to 78 μg/L.

Problem and Research Objectives

As the demand for safe drinking water increases, rainwater harvesting is emerging as an alternative water resource. Currently, there are no national standards or regulations for the quality of rainwater harvested at individual residences [1]. Moreover, several infectious diseases have been attributed to the consumption of untreated harvested rainwater [2]. Therefore, if harvested rainwater is intended for potable usage, it should be disinfected. In the United States, ultraviolet light and chlorine are both commonly used for the disinfection of rainwater. Chlorine has the advantage of being more cost-effective. When water is disinfected using chlorine, the dissolved organic carbon (DOC) in the water reacts with chlorine to form disinfection byproducts such as trihalomethanes (THMs). The four THMs of interest in drinking water are chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$) and bromoform ($CHBr_3$). Studies have demonstrated carcinogenic effects and liver toxicity from THMs in mice [3]. The United States Environmental Protection Agency (U.S. EPA) has classified all four THMs as possible or probable human carcinogens. The U.S. EPA's maximum contaminant level (MCL) for total THMs in drinking water is 80 μg/L.

The adverse effect of THMs on human health can extend beyond drinking water to indoor air quality. For instance, chloroform is an extremely volatile compound with an outdoor air concentration below 1 $\mu g/m^3$. When chlorinated water is heated (e.g., when running a shower or using a washing machine), the chloroform readily volatilizes. Chloroform in a small shower compartment, while taking a warm shower with tap water, can reach concentrations up to 1000 $\mu g/m^3$ [4].

In a previous study, in which we analyzed harvested rainwater quality from five pilot-scale roofs (asphalt fiberglass shingle, Galvalume® metal, concrete tile, cool and green), DOC

concentrations ranged from 2 to 37 mg/L [5]. Thus, DOC concentrations in harvested rainwater are greater than or equal to those found in tap water. **The presence of DOC in harvested rainwater could lead to the production of THMs after chlorination, which has consequences for human health.** Thus, the purpose of this project was to assess THM formation in harvested rainwater under typical chlorination conditions that are used in the field.

Materials/Methodology

Harvested rainwater was collected from one asphalt fiberglass shingle full-scale roof in Austin, Texas. The harvested rainwater was treated with or without filtration and with chlorination for a variety of contact times: (1) chlorination with a target residual of 2 mg/L after 10 minutes followed by quenching with sodium thiosulfate; (2) filtration and chlorination with a target residual of 2 mg/L after 10 minutes, followed by quenching with sodium thiosulfate; (3) chlorination with a target residual of 2 mg/L after 10 minutes; total contact time of 7 hours; (4) filtration and chlorination with a target residual of 2 mg/L after 10 minutes; total contact time of 7 hours.

For the experiments with filtration, a 10-micrometer (μm) filter followed by a 1-μm glass microfiber filter was used. An absolute 1-μm filter is the only way to fully protect against *Cryptosporidium* and *Giardia* cysts. Without the removal of these cysts, water is considered non-potable [6]. The harvested rainwater was disinfected using a sodium hypochlorite solution (household bleach) to achieve a target residual of 2 mg/L after a contact time of 10 minutes. Some households chlorinate their harvested rainwater as it enters the house; this method is known as point-of-entry treatment [6]. The typical chlorine contact time is simply the amount of time required for the water to travel through the house's plumbing system (approximately 5-10 minutes, depending on the house), so a contact time of 10 minutes was chosen to simulate a typical residence time in a house. If water flow is stopped, then the reaction between chlorine and DOC will continue while the water stagnates in the pipes; thus, we also chose to examine THM formation after a 7-hour contact time.

Some THM analyses were conducted at DHL Analytical (Round Rock, TX), and some were conducted at the University of Texas at Austin. Liquid-liquid extraction was used to extract THMs from the water samples using pentane as the extractant. 1,1,1-trichloroethane (TCA) was used as the internal standard. THM concentrations were measured by gas

chromatography using a Hewlett Packard 6890A GC. Analyses used a splitless glass injector liner, a 60 m HP-5 capillary column, and an electron capture detector. Helium was the carrier gas, and the pressure through the column remained constant at 16.5 psi. The injection volume was 2 µL. The injector temperature was 200°C, and the detector temperature was 325°C. The oven program was: 32°C for 9 min, 10°C/min ramp to 40°C, 40°C for 3 min, and 15°C/min ramp to 150°C [7]. The run time per sample was 20 min.

Principal Findings

Harvested rainwater was collected from a full-scale residence in Austin, TX. The harvested rainwater had a DOC concentration of 3.1 mg/L and a turbidity of 1.9 nephelometric turbidity units (NTU).

As described above, the water was treated in four ways, and THMs were measured. Figure 3 shows that chloroform was the dominant THM detected. Low concentrations of bromodichloromethane and dibromochloromethane were detected, but no bromoform was detected.

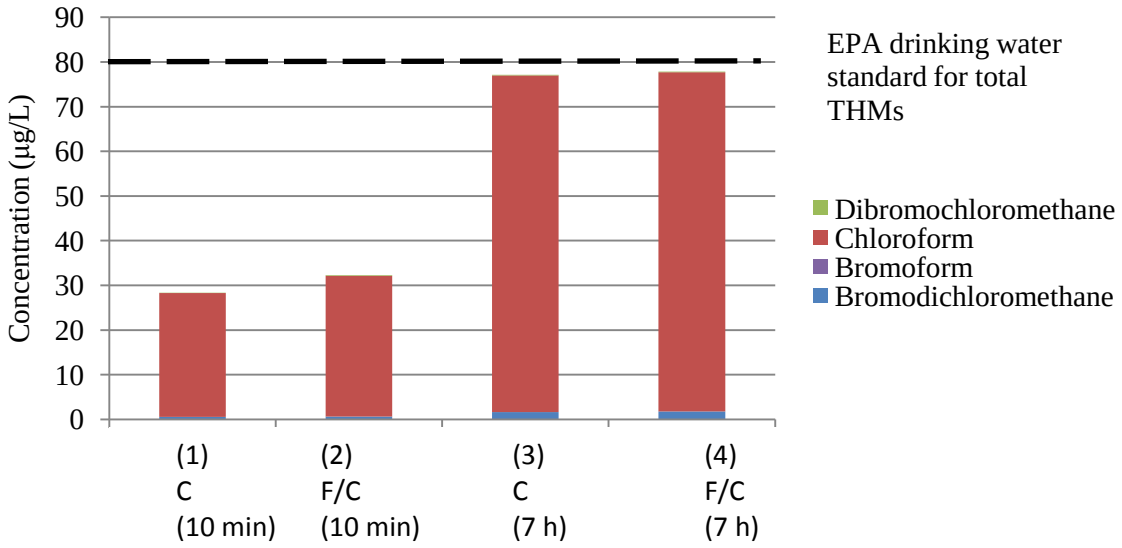

Figure 3: THM concentrations from treated rainwater harvested from a full-scale asphalt fiberglass shingle roof. F=filtration and C=chlorination (for a total contact time of 10 minutes or 7 hours)

Figure 3 indicates that total THMs were below the U.S. EPA drinking water standard of 80 μg/L when the water was chlorinated for only 10 minutes. However, total THMs approached the EPA drinking water standard when the chlorine contact time was 7 hours. It is possible that total THMs would have exceeded the drinking water standard if the contact time was longer (e.g., chlorinated water stagnated in the pipes overnight or if the user batch-chlorinated in the storage tank) or if the DOC concentration were higher. Since this particular water did not have a high turbidity, filtration of the water prior to chlorination did not have a significant impact on THM formation.

Future Work

We have just built a treatment system that more closely simulates a typical, residential treatment system. Chlorine residuals of 0.2 and 2 mg/L after 10 minutes will be targeted. An ANSI/NSF 53 certified carbon filter will be used downstream of chlorination. Rainwater harvested from a variety of roofing materials will be analyzed to determine how the roofing material affects THM formation.

Significance

Harvested rainwater is increasingly used for potable purposes. If a user treats that water by chlorination, there exists a potential for the generation of harmful THMs. Our work is significant because it demonstrated THM formation, approaching the U.S. EPA drinking water standard for total trihalomethanes, under chlorination conditions typical of a residential application.

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