Portable Water Treatment and Trihalomethane Formation

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BACKGROUND

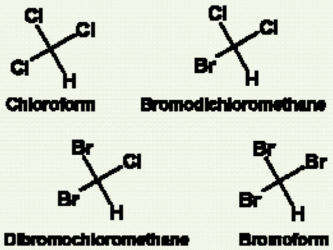

Figure 1: Regulated trihalomethanes

Trihalomethanes (THMs) are volatile organic compounds produced as byproducts of drinking water disinfection by chlorine. Due to their known human carcinogenicity, these disinfection byproducts (DBPs) are regulated by the U.S. Environmental Protection Agency at a maximum contaminant level (MCL) of 80 µg/L total THMs (THM4) as the sum of $CHCl_3$, $CHBrCl_2$, $CHBr_2Cl$, and $CHBr_3$ (Fig. 1) [1]. THM formation is a function of the dose of chlorine and the amount of chlorine consumed by the dissolved organic carbon (DOC) in the source water. This research focused on portable water disinfection methods like those used by hikers (Fig. 2), both with and without chlorine, to determine the optimum treatment method for THM minimization.

METHODS

Camping Water Treatment: Comparative portable treatment plans are outlined in Fig. 2, and described in Table 1.

Chlorine Detection: A Hach colorimeter was used to measure free and total chlorine levels after reacting with N,N-Diethyl-p-Phenylenediamine salt (DPD) [2].

THM Analysis: Residual chlorine in 40 mL samples was quenched with ammonium sulfate, and phosphate was added to buffer at pH 5. THMs were extracted by liquid-liquid extraction and analyzed by gas chromatography with electron capture detection [3].


Figure 2: Water Treatment Methods

Method calibration solutions (2.5 to 100 µg/L) were analyzed to make calibration curves and quantify each THM relative to the internal standard (IS) 1,2-Dibromopropane.

Table 1: Treatment Advantages and Disadvantages

Treatment	Pros	Cons
MSR Sweetwater (NaOCl)	Light weight Inactivates viruses	Can leave chemical taste
Granular Activated Carbon (GAC)	Eliminates bacteria and protozoa Improves the taste of water in addition to treating it Uses no chemicals	Heavier Requires work Larger to pack or carry Does not kill viruses
UV Light	Light and Quick, useful at low temps Uses no chemicals Kills bacteria, viruses, protazoa	Requires clear water sources Does nothing to improve aesthetic quality of water or remove sediment
Pur Packets ($Ca(OCl)_2$ + $FeSO_4$)	Light Removes dirt, cysts, and pollutants, and kills bacteria and viruses	Requires 30 minutes of wait time Limited to dosing 10 liters of water per packet
MIOX	Light weight Easily doses large volumes of water Inactivates viruses, bacteria, giardia, and potentially cryptosporidium.	Difficult to use – requires testing of water and possible retreatment Requires 30 minutes to 4 hour wait time

Figure 3: Seattle Sampling Sites [4]

Table 2: Site Codes

Location	Letter
Silver Lake, Everett	A
Duwamish River	B
Portage Bay	C
Drumheller Fountain	D
Union Bay Waterfront Activities Center	E
Green Lake	F
Ballard Locks	G
Gas Works Park	H
Ship Canal Trail	I

Table 3: Sampling Dates

Group	Location	Date
1	A	1/23/2008 *
2	B	2/6/2008
3	C	2/6/2008
4	C	2/8/2008
5	C	2/19/2008
6	C	2/20/2008
7	D	3/4/2008
8	E	3/5/2008
9	C	1/14/2009
10	F	1/28/2009
11	D	1/29/2009
12	G	2/7/2009
13	H	2/11/2009
14	I	2/24/2009
15	C	2/26/2009

Sampling Sites: Grab water samples were collected in 1L glass bottles at 9 sites in the Seattle/Everett* area during January and February of 2008 and 2009 (see above), and were stored at 4°C until filtration (7 µm) and treatment.

RESULTS & DISCUSSION

By Treatment Path (Table & Figure 4): UV Light treatment (no chlorine) had the lowest levels of THM4, followed by NaOCl + GAC, where GAC filtered out THMs and chlorine. NaOCl alone and MIOX made the most THMs. Multiple treatments of Portage Bay allowed comparison of treatments on the same source water.

By Location (Table & Figure 5): Only Duwamish River and Drumheller Fountain produced THM4 levels above the MCL. This could be attributed to high DOC in the source water. Inland sites like Green Lake had the lowest levels while sites close to salt water intrusion areas presented the higher levels of THM4 due to higher source bromide concentrations.

By Chlorine Consumed (Figure 6): The THM4 levels show some correlation with the chlorine consumed by the source water. The highest chlorine consumption was due to doses greater than the manufacturer recommended dose.

Table 4: THM formation for each treatment

Treatment	Average	Stdev	Min	Max
All	38	61	bdl*	341
GAC + NaOCl	41	88	5	341
NaOCl	61	59	16	210
NaOCl + GAC	10	5	5	17
MIOX NaOCl	43	11	34	55
Ca(OCl)2 + FeSO4	9	3	6	14
UV Light	1	2	bdl	3
UV Light + NaOCl	53	50	17	137

*bdl = below detection limit

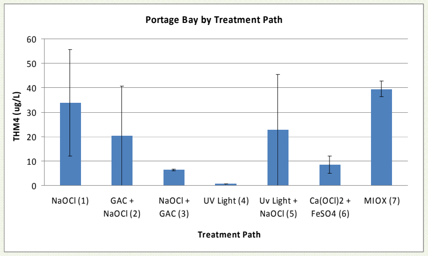

Figure 4: THM formation in Portage Bay water (C)

Table 5: THM formation from each sampling site

Letter	Site	Average	Stdev	Min	Max
	All	38	61	bdl	341
A	Silver Lake, Everett	16	15	5	33
B	Duwamish River	161	42	136	210
C	Portage Bay	24	20	1	65
D	Drumheller Fountain	88	128	5	341
E	Union Bay Waterfront Activities Center	22	1	21	23
F	Green Lake	6	2	3	8
G	Ballard Locks	32	15	17	55
H	Gas Works Park	12	13	bdl	26
I	Ship Canal Trail	10	8	bdl	15

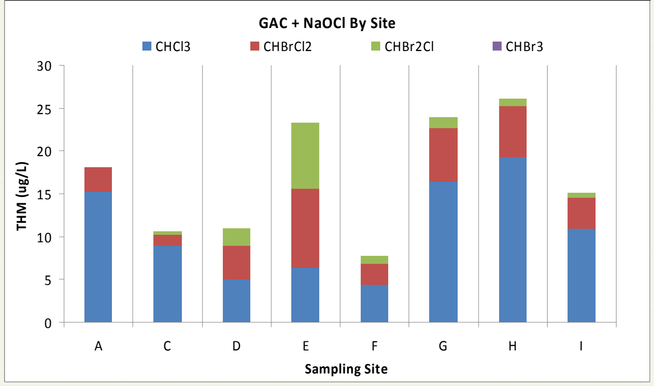

Figure 5: THM speciation after GAC filtration & chlorination

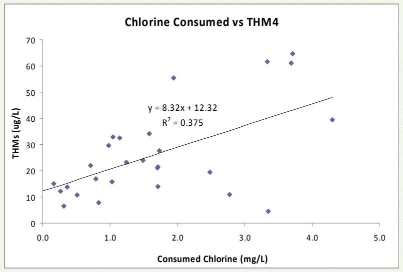

Figure 6: THM formation and chlorine consumed

CONCLUSIONS

Chlorination followed by GAC gave the lowest levels of THMs. In order to minimize THM levels one should use UV light treatment or GAC alone. Source water quality is equally important to treatment path in order to minimize THM formation. In general, the manufacturer recommended treatment procedures do not produce THMs above the MCL for drinking water.

ACKNOWLEDGEMENTS

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REFERENCES:

[1] U.S. EPA, National primary drinking water regulations: disinfection and disinfection byproducts, Fed. Register 63 (241) (1998) 69389. **[2]** Standard Methods for the Examination of Water and Wastewater. Method 4500-Cl. Ed. Clesceri L.S., Greenberg A.E., and Eaton A.D.. 20th ed. APHA AMWA WEF, 1998 **[3]** U.S. EPA, Method 551.1, Cincinnati, OH, 1995. **[4]** "Seattle Base Map." Map. Seattle.gov. 2009. City of Seattle. 5 May 2009 <http://www.cityofseattle.net/html/citizen/maps_seattle.htm>.