

Direct Injection, Simple and Robust Analysis of Trace-Level Bromate and Bromide in Drinking Water by IC with Suppressed Conductivity Detection

Wasiu Lawal¹, Jay Gandhi^{2,*}, and Chunlong (Carl) Zhang¹

¹University of Houston Clearlake and ²Metrohm USA Inc.

Abstract

Bromide is ubiquitously found in drinking water. It is introduced into source water primarily by contact with bromide-containing soils or seawater having high bromide content. Bromide is converted into carcinogenic bromate during ozonation processes employed in some drinking water and wastewater treatment plants. Therefore, monitoring of bromate in drinking water and its precursor bromide in source water is required. The purpose of this study was to survey bromide and bromate concentrations in randomly selected bottle waters of various brands and several tap water samples in the coastal Houston area using a direct-injection ion chromatography (IC) and a suppressed conductivity system. The method employs a simple isocratic IC with loop injection with calculated detection limit of 0.009 µg/L for bromate and 0.028 µg/L for bromide (250-µL sample volume). Allowing the detection of both species at the µg/L level in drinking water, this method does not require specialized instrumentation such as two-dimensional IC, expensive sample preparation, or post-column reactions. The results show that, whereas bromate remains undetected in all five tap water samples, there are significant high concentrations of bromide in the coastal Houston area (294.79 ± 56.97 µg/L). Its link to potential seawater intrusion need to be further investigated. For bottle water samples randomly collected, 18.2% (2 out of 11) showed detectable amount of both bromide and bromate. The detection of bromate coincides with those bottle water samples that underwent ozonation treatment. Further sample campaign with exclusively ozonated bottle water samples ($n = 19$) showed 100% detection rate for both bromide and bromate. The 99% confidence intervals were 14.45–37.97 µg/L and 0.32–2.58 µg/L for bromide and bromate, respectively. The highest level of bromate among all ozonated bottle water samples was 7.57 µg/L, a concentration close to the U.S. EPA prescribed limit for drinking water standard. Regression analysis indicated that although a positive correlation exists between bromide and bromate concentrations, such a correlation is not statistically significant. This finding is not unexpected since a variety of other parameters in the ozonation process (such as water quality, ozone dose, and time in addition to bromide concentration) affect the formation of bromate. Our results strongly suggest that cautions should be exercised to examine the potential formation of bromate when

source water from coastal zone undergoes ozonation treatment. Another strong proof of our findings is that all the tap waters collected were treated in jurisdictions that do not use ozonation for disinfection. The fact that none of these tap water samples contained bromate (despite an abundance in bromide) proves our hypothesis even further.

Introduction

Ozonation is an ozone (O₃)-based disinfection process as well as an advanced oxidation process used to inactivate pathogens and oxidize organic compounds in drinking water (either for municipal drinking water supplies or for bottled waters) (1–4). The most common disinfection process in water and wastewater treatment plants uses chlorine gas. UV detection is also increasingly used disinfection process in many European countries (2,5). However, in many circumstances, ozone is preferred because it not only kills bacteria and viruses; ozone also improves the taste and removes odorous compounds at the trace levels (1). Ozone can also oxidize inorganic iron and manganese from their reduced oxidation states and, in some cases, removes turbidity (2).

One problem with ozonation, however, is that it reacts with bromide (Br⁻, a common anion found in most water sources) to form bromate (BrO₃⁻) (6–13). Bromate is a “possible human carcinogen”, according to the World Health Organization (WHO) (14). Termed a disinfection by-product (DBP), bromate is esti-

Table I. Analytical Conditions Using IC with Conductivity and UV Detector

Analytical Parameters	Parameter Values
Separation Column	Metrosep A Supp 7-250/4.0
Suppressor type	MSM (Metrohm suppressor module)
Eluent	3.5 mM Na ₂ CO ₃
Eluent flow rate	0.7 mL/min
Column temperature	45°C
Run time	40 min
Injection volume	100 and 250 µL

*Author to whom correspondence should be addressed.

Table II. Bottled Water Sample Information

Sample ID	Purification process	Sampling experiment	Batch and other information
A	Reverse osmosis	Experiment 1	Purchased 03/28/2009 (WalMart, Dunvale)
B	Carbon filtration, UV treatment, microfiltration, ozonation	Experiment 1 and 2	B* - Pkd 02 27/09 Purchased 03/28/2009 (WalMart, Dunvale) B [†] - No batch information. Purchased 07/04/2009 (WalMart, Dunvale)
C	Not specified	Experiment 1	Purchased 03/28/2009 (WalMart, Dunvale)
D	Reverse osmosis, distillation	Experiment 1	Purchased 03/22/2009 (Sam's Club Rice Blvd)
E	Not specified	Experiment 1	Purchased 03/29/2009 (99 cent store, Westheimer @ Hillcroft)
F	Not specified	Experiment 1	Purchased 03/29/2009 (99 cent store, Westheimer @ Hillcroft)
G	Reverse osmosis	Experiment 1	Purchased 03/28/2009 (WalMart, Dunvale)
H	Reverse osmosis, carbon filtration, ozonation	Experiment 1 and 2	H* - 1000 mL 8189DP4 Purchased 03/28/2009 (WalMart, Dunvale) H [†] - 591 mL, No batch information. 06/19/2009 (Target, Meyerland)
I	Vapor distillation	Experiment 1	Purchased 03/28/2009 (WalMart, Dunvale)
J	Reverse osmosis	Experiment 1	Purchased 03/28/2009 (WalMart, Dunvale)
K	Not specified	Experiment 1	Purchased 03/29/2009 (99 cent store, Westheimer @ Hillcroft)
L	Ozonation	Experiment 2	No batch information for this brand. L* - Collected 07/05/09 in the Westchase area. L [†] - Collected 07/11/09 in Clear Lake area.
M	Not specified	Experiment 2	M* - Best by 03/18/11 Purchased 06/28/2009 (CVS, Westchase) M [†] - Best by 02/24/10 Purchased 07/11/09 (CVS, Clear Lake)
N	Carbon filtration, microfiltration, ozonation	Experiment 2	Purchased 06/21/2009 (Fiesta, Bellaire @ Gessner)
O	Carbon filtration, UV treatment, microfiltration, ozonation	Experiment 2	Purchased 06/14/2009 (Valero Gas station, Westpark @ Gessner)
P	Carbon filtration, ozonation	Experiment 2	P* - Sell by 10/10/2009 Purchased 06/25/2009 (HEB Bellaire, TX) P [†] - Sell by 11/04/2009 Purchased 07/11/2009 (HEB, Clear Lake)
Q	Carbon filtration, Ozonation	Experiment 2	Q* - Sell by 09/02/09 Purchased 06/25/2009 (HEB Bellaire, TX) Q [†] - Sell by 10/30/09 Purchased 07/11/2009 (HEB, Clear Lake)
R	Ozonation	Experiment 2	R* - Sell by Jun 16, 2009 R [†] - Sell by Jan 31, 201
S	Ozonation	Experiment 2	Purchased 06/22/2009 (Macy's, West Oaks Mall)
T	Steam distillation, filtration, ozonation	Experiment 2	Purchased 06/21/2009 (Fiesta, Bellaire @ Gessner)

* Denotes the first batch of samples purchased.

† Denotes the second batch of samples that was purchased at a later date.

mated to cause an excess life-time cancer risk of 1:10⁴ at 5 µg/L. The current regulatory limit for bromate in water however is 10 µg/L. The reason for this high concentration is based on the current analytical capabilities (15). In fact, the limit used to be 25 µg/L (6,16,17) for the same reason, but analytical improvements have allowed it to lower to its current level. In spite of this, the U.S. EPA has set a maximum contaminant level goal of zero (15). Hence, there is a need for more simple yet advanced technologies in order to enable quick and reliable determinations at the sub-µg/L levels.

Issues in Bottled Water Quality

According to the British Soft Drinks Association (BSDA), the practice of packing water in bottles for human consumption started during the Tudor times around the 17th century (3). This practice increased and became more popular in the past century, especially the last 20 years. In fact, according to the Sierra Club (18), Americans spent \$4 billion on bottled water in 1999, a number that must have increased dramatically in the last 10 years. According to Abdula'aly et al. (19), bottled water is perceived to taste better, have fewer impurities, and confer higher social status. This perception may be fueled by the fact that bottled water costs 1,900 times more than tap water, hence the thinking that "if it costs so much more then it must be of much better quality". The reality, however, based on numerous studies/reports is that this is simply not the case. A recent study released by the Environmental Working Group (EWG) (20) in October 2008 found a total of 38 different pollutants (DBPs, fertilizer by-products, and pain medication) in the 10 brands collected. Some brands actually had identical properties (compositions) with the municipal supplies they came from, even though they had supposedly gone through some "purification" processes. In 2003, eight bottled water firms lost their licenses in India (21) for containing high doses of pesticides while other tests in places like Bangladesh (22) and Mexico (23) revealed the presence of bacteria like *Escherichia coli*, *Shigella*, and *Enterobacter* in bottled water. There is also the issue of the bottles (used for packaging) leaching contaminants like Bisphenol A (18) and antimony (24) into water, while another study (9) that is of particular importance to this one showed the presence of oxyanions (including bromate) in all but 1 of 21 brands collected (9). Eleven of those samples contained levels of bromate above 1 µg/L with notable highs being 14, 28, and 76 µg/L, all which are above the regulatory limit of 10 µg/L. This study, however, did not relate its findings to the presence of bromide.

Apparatus, Reagents, and Related Information

Anion standards used in various experiments of this project were purchased as follows. Fluoride, phosphate, and bromate came as sodium salts and purchased from Fisher Scientific (Fair Lawn, NJ) with purities of 99.2%, 99.8%, and 100.1%, respectively. Sulfate and nitrate also came as sodium salts and were purchased from J.T. Baker (Phillipsburg, NJ) and had purities of 99% and 100.2%, respectively. Nitrite was purchased as a potassium salt from Aldrich (Milwaukee, WI) with a purity of 97%. Bromide also came as a potassium salt from BDH Chemicals (Poole, England) with a purity of 98%, and chloride was purchased as a sodium salt from Mallinckrodt Chemicals (Phillipsburg, NJ) with a purity of 99%. Sodium carbonate (eluent) came from Fisher Scientific with a purity of 98%. Sulfuric acid (suppressor solution) came from Mallinckrodt Chemicals with a purity of 95.7%, and phosphoric acid (also suppressor solution) was purchased from J.T. Baker with a purity of 96%. All anion stock solutions were prepared to contain 1000 mg/L of the target anion. The eluent (Na_2CO_3) stock solution was 0.35 M (eluent for daily use was prepared by diluting 10 mL of stock solution into 1 L of deionized water), and the suppressor solution contained 100 mM and 50 mM of sulfuric acid and phosphoric acid, respectively. All solutions were prepared by dissolving the reagents in Milli-Q ultrapure deionized water (Millipore, Bedford, MA) and diluted as necessary.

Instrumentation

The method for the analysis of bromate and bromide was based on the EPA Method 300.0 for the determination of inorganic anions using ion chromatography (28). Key modifications to the standard method in this study included the use of a high capacity/more targeted column as well as an increased sample loop. This column is anion exchange column, polyvinyl alcohol with quaternary ammonium groups, and it has pH range of 3–12, so either carbonate or hydroxide eluents may be used with or without gradient. The EPA method uses a 50- μL sample loop.

The instrument used for this study was a Metrohm (Herisau, Switzerland) Model 850 professional IC with suppressed conductivity. The eluent (mobile phase) was 3.5 mM Na_2CO_3 . Other chromatographic conditions are listed in Table I.

Tap water and bottle water sample collections

Sample collections were carried out in two experiments. During the first experiment, 11 bottled water samples (numbered A through K, Table II) were randomly collected from grocery stores around the Houston area as well as five tap water samples (numbered 1 to 5, Table III) from different parts (Clear Lake, Kemah, Pasadena, Pearland, and Westchase) of the metropolitan area. As shown in Table III, only 2 of the 11 (A through K) randomly collected bottle water samples were ozonated. Even though the sample size is relatively small, it is expected to obtain variations of analytes and the detection rate for bromate.

The second experiment was focused on bottled waters that had

only undergone ozonation. A total of 19 ozonated bottle water samples were collected during Experiment 2, including 9 new (numbered from L to T) and two of these samples (samples B and H) that were previously collected during Experiment 1. Of these 19 samples, there were actually 12 different brands as 7 of the brands were collected in 2 batches (denoted as * and † in the table) to get some measure of possible variations among various batches.

Tap water samples were collected in U.S. EPA approved containers directly from the faucet (after thorough rinsing). These samples were generally clear on appearance and were kept immediately in an ice cooler until they reached the lab where they were transferred to the refrigerator. All samples (tap and bottled water) were stored at 4°C until analysis.

Results and Discussion

Method detection level study

The method detection limit (MDL) is the minimum concentration of an analyte that can be identified and quantified with 99% confidence that the analyte concentration is greater than zero (28). To determine the MDL, we analyzed seven replicates of the same sample of known concentration (2–3 times the estimated instrument detection limit). The MDL is then calculated as follows:

$$\text{MDL} = t \times \text{SD}$$

where t = Student's t -value for a 99% confidence level and SD = standard deviation estimated with $n - 1$ degrees of freedom. For seven replicates, $t = 3.14$ at 99% confidence level.

Table III. Tap Water Sample Information

Sample ID	Sampling date	Location	Description	Disinfectant process	Sampling location type
1	04/02/2009	Clear Lake	Stage 1	Chloramination	Commercial
2	04/02/2009	Kemah	Stage 1	Chloramination	Commercial
3	04/02/2009	Pasadena	Stage 1	Chloramination	Commercial
4	03/29/2009	Pearland	Stage 1	Chloramination	Commercial
5	03/29/2009	Westchase	Stage 1	Chloramination	Residential

Table IV. Method LOD Study Based on 100- μL Sample Injection Loop

Replications	Bromate ($\mu\text{g/L}$)	Bromide ($\mu\text{g/L}$)
MDL 1-1	0.551	2.502
MDL 1-2	0.534	2.511
MDL 1-3	0.542	2.504
MDL 1-4	0.549	2.549
MDL 1-5	0.555	2.498
MDL 1-6	0.539	2.501
MDL 1-7	0.549	2.532
Mean	0.546	2.514
Standard deviation	0.0074	0.0193
Method detection limit	0.023	0.060

Two MDL studies were conducted during the course of this project. These two MDLs correspond to sample injection volumes (Table IV and Table V). The first was using a 100- μ L sample loop, which resulted in an MDL of 0.023 μ g/L for bromate and 0.060 μ g/L for bromide. The second MDL study was done using a 250- μ L sample loop and resulted in an MDL of 0.009 μ g/L for bromate and 0.028 μ g/L for bromide.

From Table IV and Table V, it is clear that both tests using the 100- μ L and 250- μ L sample loops achieved results better than expected (sub- μ g/L). With bromate detection limits of 0.023 μ g/L and 0.009 μ g/L, respectively, both methods have shown that they are capable of detecting trace levels of bromate and bromide in water samples. It is also clear from these results that the bigger sample loop did in fact lead to a better detection limit (0.009 μ g/L). Both detection limits are an improvement on the 0.95 μ g/L achieved in the previous study from this laboratory and also on the detection limits achieved in all the literature referenced for

	Bromate (μ g/L)	Bromide (μ g/L)
MDL 1-1	0.105	0.521
MDL 1-2	0.104	0.525
MDL 1-3	0.112	0.514
MDL 1-4	0.109	0.519
MDL 1-5	0.105	0.499
MDL 1-6	0.109	0.523
MDL 1-7	0.109	0.513
Mean	0.108	0.516
Standard deviation	0.0029	0.0088
Method detection limit	0.009	0.028

Analyte	Calib-1*	Calib-2*	Calib-3*	Calib-4*	Calib-5*
Fluoride	0.245914	0.45033	1.088078	2.399533	4.518192
Bromate	0.002967	0.005434	0.013128	0.028952	0.054515
Chloride	2.647644	4.84851	11.71486	25.83472	48.64539
Nitrite	0.263239	0.482057	1.164736	2.568585	4.836508
Bromide	0.675887	1.237722	2.990557	6.595056	12.41814
Nitrate	1.265304	2.317095	5.598512	12.34637	23.24754
Phosphate	2.10379	3.852575	9.308505	20.52799	38.65311
Sulfate	3.059569	5.60285	13.53748	29.85412	56.21372

* Parts per million.

Anion	Calibration range (μ g/L)	R^2 value
Fluoride	246.00–4518.00	0.999921
Bromate	2.95–54.6	0.970311
Chloride	2648.00–48646.00	0.999998
Nitrite	263.00–4836.00	0.999993
Bromide	676.00–12418.00	0.992916
Nitrate	1265.00–23248.00	0.999974
Phosphate	2104.00–38653.00	0.999810
Sulfate	3060.00–56214.00	0.999997

this study, the best of which was 0.045 μ g/L using liquid chromatography–tandem mass spectrometry (10).

Stage 1 (analysis of anions and oxyhalides in drinking water): Calibration information

Figure 1 represents the chromatogram for typical calibration standard for anions and bromate. For the first stage of this study, calibration standards containing bromate as well as other stan-

Sample ID	Bromate (μ g/L)	Bromide (μ g/L)	Average
Sample 1	nd	236.593	236.6985
Sample 1 Dup	nd	236.804	
Sample 2	nd	382.087	382.236
Sample 2 Dup	nd	382.385	
Sample 3	nd	301.59	301.711
Sample 3 Dup	nd	301.832	
Sample 4	nd	251.564	251.456
Sample 4 Dup	nd	251.348	
Sample 5	nd	300.831	300.8265
Sample 5 Dup	nd	300.822	

* Not detected.

Anions	Non-ozonated bottle water samples ($n = 9$)			Ozonated bottle water samples ($n = 2$)			All samples ($n = 11$)	
	$\bar{x} \pm s$ (μ g/L)	CV (%)	Detection rate (%)	$\bar{x} \pm s$ (μ g/L)	CV (%)	Detection rate (%)	Detection rate (%)	
Br ⁻	Nd	–	0	52.82	53.93	102	100	18.2
BrO ₃ ⁻	Nd	–	0	1.09	0.34	31.3	100	18.2

Sample ID	Bromate (μ g/L)		Bromide (μ g/L)	
Sample A Dup	nd		nd	
Sample B	0.86	0.851	14.697	14.688
Sample B Dup	0.842		14.679	
Sample C	nd		nd	
Sample C Dup	nd		nd	
Sample D	nd		nd	
Sample D Dup	nd		nd	
Sample E	nd		nd	
Sample E Dup	nd		nd	
Sample F	nd		nd	
Sample F Dup	nd		nd	
Sample G	nd		nd	
Sample G Dup	nd		nd	
Sample H	1.343	1.335	90.177	90.952
Sample H Dup	1.327		91.727	
Sample I	nd		nd	
Sample I Dup	nd		nd	
Sample J	nd		nd	
Sample J Dup	nd		nd	
Sample K	nd		nd	
Sample K Dup	nd		nd	

standard anions (fluoride, bromate, chloride, nitrite, bromide, nitrate, phosphate, and sulfate) were prepared from the stock solutions mentioned earlier. The range of actual measured anion concentrations at this stage is given in Table VI. A linear regression calibration line was obtained for all anion standards studied with an indication of linearity given by R^2 values. It is important to note here that the reason why stage 1 involved a full range of analysis of standard anions (commonly found in drinking water) in addition to bromate is to ascertain that none of these anions co-elute/interfere with bromate in this study. As this fact was already proven in stage 1 that stage 2 was more focused in proving the correlation between bromide, ozonation, and the presence of bromate.

Sample analysis of bromate and bromide in tap water samples

For the five tap water samples collected, Table VIII shows that none of the samples collected contains any bromate, even though they all contain an abundance of bromide (mean \pm SD = 294.59 ± 56.97 $\mu\text{g/L}$).

A 2005 presentation (33) by the Texas Commission for Environmental Quality (TCEQ) shows that Texas has a lot of naturally occurring bromide in its water sources, most especially in West Texas and Gulf with concentrations ranging from 0.2 to 1.2 mg/L. The bromide concentrations in five tap water samples measured in this study fall within this range. Information gathered from the city of Houston, as well as the cities of Pasadena and Pearland (under whose jurisdiction some of our sampling sites fell) (34–36) revealed that all these waters underwent chloramination as the disinfection process rather than ozonation.

Anion	Calibration range ($\mu\text{g/L}$)	R^2 value
Bromate	0.100–10.00	0.999900
Bromide	0.625–25.00	0.997400

* The calibration curves for both bromated and bromide in Stage 1 and 2 are shown in Figure 3.

Sample ID	Replicates (n)	Bromide ($\mu\text{g/L}$)	Bromate ($\mu\text{g/L}$)
B	4	14.47	0.9
H	4	1.91	1.26
J	2	2.58	1.89
L	4	5.95	1.49
M	4	59.79	0.6
N	2	40.21	0.82
O	2	25.71	1.13
P	4	61.41	7.57
Q	4	42.07	0.175
R	4	12.13	0.305
S	2	28.18	0.23
T	2	20.09	1.01
Mean \pm standard deviation		20.21 ± 20.78	1.45 ± 1.99
95% confidence interval		14.45–37.97	0.32–2.58

* All bottled waters were ozonated.

Additionally, according to the aforementioned TCEQ presentation (33), chloramination produces much less disinfection by products than ozonation (more specifically, chloramination does not react with bromide to form bromate). This might explain the absence of bromate in all test tap water samples. Questions arise as to whether seawater intrusion could be the source of bromide in the test samples because source waters in this area come from Lake Houston and Lake Conroe. This potential link to seawater intrusion needs to be further investigated.

Bromate and bromide analysis in bottled water (stage 1)

Table IX summarizes the results from 11 randomly collected bottle water samples during stage 1. Results for bottled waters presented in Table X shows that only 2 of 11 brands contained bromate (average of 0.850 $\mu\text{g/L}$ in sample B and 1.335 $\mu\text{g/L}$ in sample H). The same two samples were also the only ones to show the presence of bromide (14.688 $\mu\text{g/L}$ in sample B, 90.952 $\mu\text{g/L}$ in sample H). Out of 11 random samples, the detection rates for both species were 18.2%. In all the nine non-ozonated bottle water samples, both bromide and bromate were below detection limit.

The relative concentrations of bromide and bromate in two ozonated bottle water samples are plotted in Figure 2. It appears that higher bromate concentration in sample H is correlated with the high bromide concentration in the same sample.

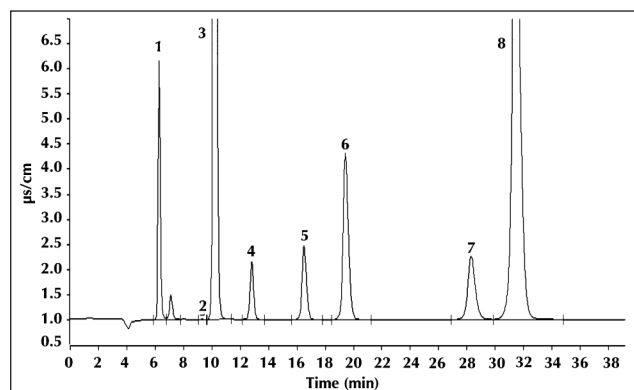


Figure 1. A typical ion chromatogram showing the separation of bromate and bromide. Peak numbers are as follows: Fluoride, 1; Bromate, 2; Chloride, 3; Nitrite, 4; Bromide, 5; Nitrate, 6; Phosphate, 7; Sulfate, 8.

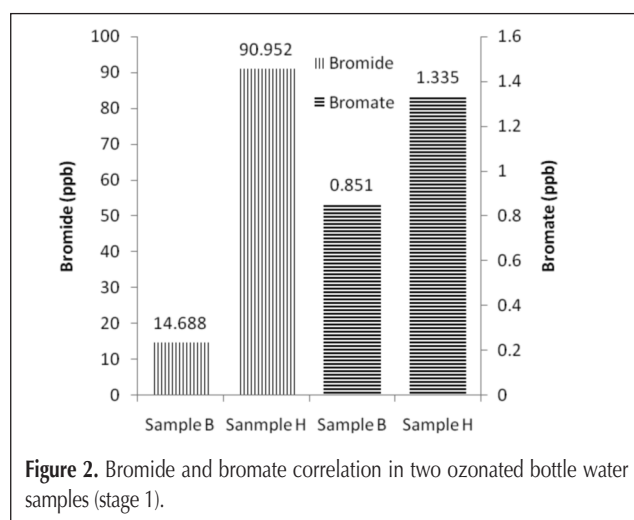


Figure 2. Bromide and bromate correlation in two ozonated bottle water samples (stage 1).

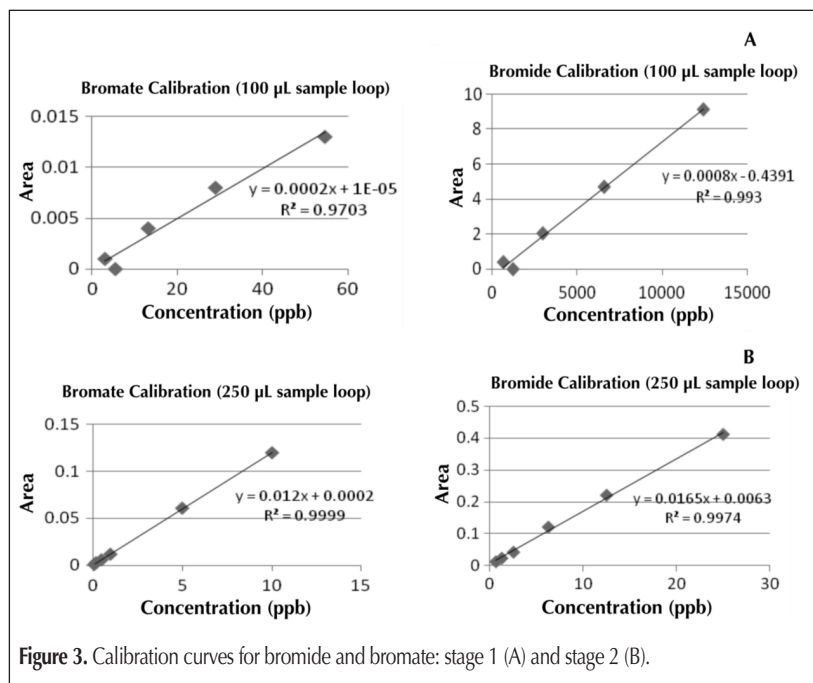


Figure 3. Calibration curves for bromide and bromate: stage 1 (A) and stage 2 (B).

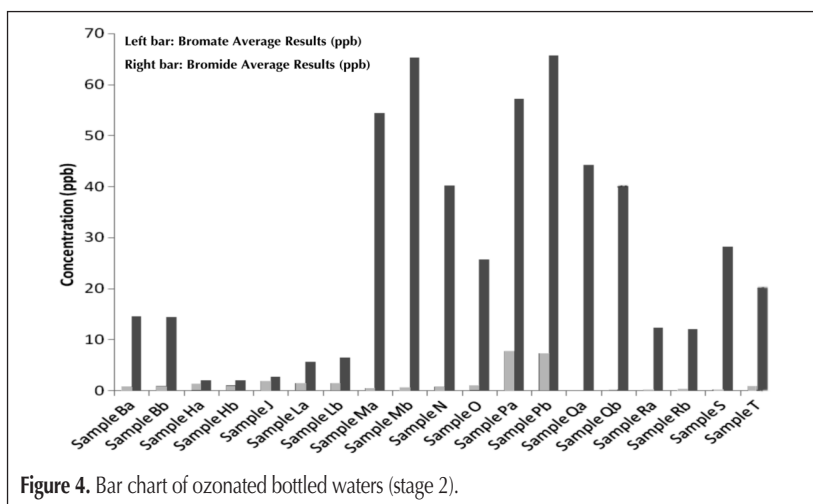


Figure 4. Bar chart of ozonated bottled waters (stage 2).

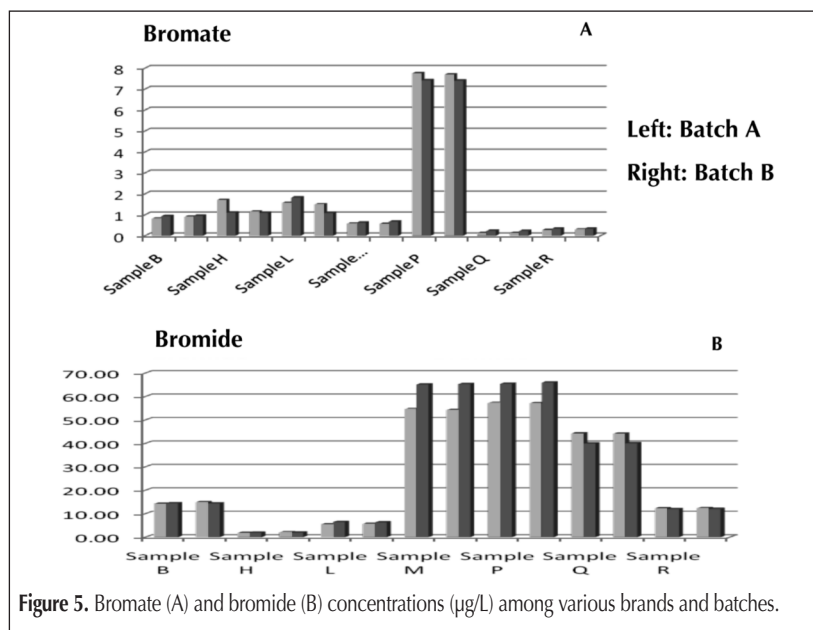


Figure 5. Bromate (A) and bromide (B) concentrations ($\mu\text{g/L}$) among various brands and batches.

Stage 2 (focused approach for ozonated drinking water): Calibration information (Figure 3, Table XI)

The concentrations of both bromide and bromate in ozonated bottle water and the correlation between bromide and bromate in bottle water samples were further investigated in stage 2, where only ozonated bottle water samples were collected. As shown in Table XII, all samples collected during stage 2 contained both bromate and bromide. Concentrations of both bromide and bromate showed great variations. The coefficient of variation (CV) estimated from the mean and standard deviation were 102% and 137% for bromide and bromate, respectively. The 99% confidence level for bromide and bromate were 14.45–37.97 $\mu\text{g/L}$ for bromide and 0.32–2.58 $\mu\text{g/L}$ for bromate. It is noted that about half of the samples had bromate concentrations of less than 1 $\mu\text{g/L}$, although two samples (Pa and Pb) contained 7.72 and 7.41 $\mu\text{g/L}$ of bromate, respectively. This high concentration of bromate is of importance because it approaches to the U.S. EPA limit of 10 $\mu\text{g/L}$.

Figure 4 gives a representation of all the concentrations in ozonated bottle water samples. It is important to note here that sample H in the first stage (Figure 2) is the same sample as sample H in the second stage (Figure 4). Shown in Figure 4 are also the concentrations among two different batches (noted as * and †).

Even further statistical analysis on the seven brands that had two different batches shows that for bromate and bromide the difference in concentrations in various brands are statistically significant at the confidence level of 95%. Also, for bromate, the difference among batches is not statistically significant. This is not the case for bromide as the differences in concentration are statistically different. Figure 5A–5B shows a graphical representation of these comparisons.

Conclusion and Further Study

This study shows that if bromide is present in the sample and ozonation process for disinfection is applied, there is definite probability of forming bromate in drinking water. Also, in coastal areas, there are high levels of bromide present due to saltwater intrusion in drinking water. However, if ozonation is not used in this type of ground water, there is absence of bromate even though bromide levels are high.

Further study of correlation of quantitative formation of bromate with presence of bromide during ozonation disinfectant process will be helpful for drinking water utilities.

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