



A novel online-monitoring amplification flow injection analysis - Chemiluminescence for bromate determination in a bottled ozonated mineral water



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Abstract

A rapid and sensitive online monitoring amplification approach combined with the flow injection Chemiluminescence method (OMAFIA-CL) to evaluate bromate in ozonated bottled water samples. The process is composed of two switching valves 6-way to control the flow of sample solution containing BrO₃⁻ passing through a Cl⁻ form column to release an equivalent amount of Cl⁻, which is then passed through a (BrO₃⁻ form) column, and the released BrO₃⁻ is passed back through the first column. The accumulated amount of bromate anion is eluted by a suitable eluent after a specific time of amplification. The CL blue light is seen after adding (luminal-H₂O₂) aqueous solution to the online Br₂ solution generated by mixing NaBr and eluted KBrO₃ in a hydrochloric acid medium.

The effect of interferences was solved before an injection using the Dionex OnGuard (II Ba/Ag/H) cartridges. The calibration curve with a concentration range of (5-100 µg/L) was linear and techniques limits of detection were (3.9 µg/L) and 12 µg/L of the limit of quantification. The RSD for (10 and 80 µg/L, 7 injections) was 1.71% and 0.63%. The ion chromatography as a reference method was applied. The amplification approach was successful for the direct determination of bromate in ozonated bottled waters. The sampling rate is 120 samples per hour.

Keywords: Amplification reaction, Bromate, Chemiluminescence method, flow injection analysis, Ion exchange, Dionex onguard.

1. Introduction

According to prior research, most people believe that bottled water is a safer option than groundwater because they assume that bottled mineral water has fewer pollutants than chlorinated tap water. However, due to medical concerns, there is an increasing focus on the quality of bottled water. To eradicate hazardous microorganisms and assure their safety for human consumption, bottled water must be disinfected [1, 2]. The two most common methods for disinfection of water are ozonation and chlorination [3, 4]. The Environmental Protection Agency-USA and the European Union monitored the level of bromate anion in drinking water as well as with a permissible exposure level of 10 µg/L [5]. When water has significant quantities of bromide,

bromate can arise in drinking water as a cleaning byproduct of water ozonation. [6].

In recent years, analytical techniques for bromate with detection limits as low as (µg L⁻¹) have been presented. [7-9]. A few methods, which include a spectrophotometric method [10], FIA [11-14], High-performance LC with post-column derivatization [15], and HPLC with MS2 [16], have been mentioned for determining bromate levels in grain or similar foods. The common often technique used for bromate detection is IC, with a variety of detection types. [7, 17-24]. Every detection method has benefits and limitations. Conductivity detection, for instance, is sensitive but has little selectivity, particularly when used to diverse food products containing multiple

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ionic chemicals that could interact with bromate detection. Post-column chemical modification is a selective and sensitive approach, but it requires a more sophisticated apparatus setup and the use of hazardous derivatization chemicals. In contrast, Chemiluminescence (CL) has gained popularity in many sectors for the study of organic and inorganic chemicals since it is rapid, very sensitive, and involves reasonably priced equipment.[25-27], such as for bromate determination[28-30], Sulphite, sulphate, bromide, and Oxonium in food and water[31-34]. Bromate was detected; however, no study has been documented in the literature on CL techniques for the determination of KBrO_3 in ozonized water that relies on luminol/peroxide catalyzed by bromine production.

The goal of the current work is to apply a novel and extremely sensitive online monitoring amplification flow-injection Chemiluminescence (OMAFIA-CL) method for determining BrO_3^- in ozonated drinking water. A Large quantity can always be measured more precisely than a small; thus, the amplification can be beneficial when the error of the multiplications is not too great. It is based on the procedure developed by Weisz and Fritscher that was used to determination of trace ions [33,35]. The present study uses the two mini-ion exchange columns for amplifying bromate in ozonized bottled water. It involves the passage of a sample solution containing BrO_3^- through Cl^- form column to release an equivalent amount of Cl^- which then passes through a BrO_3^- form, and the desorbed BrO_3^- , is passed back through the first column. After definite accumulation, the amount of BrO_3^- eluted by suitable eluent and coupled with flow injection Chemiluminescence for measuring the blue light intensity generated between bromine and luminol/ H_2O_2 .

2. Experimental

Chemicals and Apparatus

All of the chemicals were analytical reagents. The (VIP® for water treatment, FDA&EPA standard, Taiwan) was used for purified and deionized water. To eliminate interferences, Dionex OnGuard II Ba (1.0 cc P/N 057093), OnGuard II Ag (1.0 cc P/N 057089), and Dionex OnGuard II H Cartridges (1.0 cc P/N 057085); the cartridge was purchased from (Thermo Scientific Dionex, USA). The flow system

employed by using two peristaltic pumps, one with six plungers (DESAGA, Heidelberg,-England) delivered Deionized water with a flow rate (1 ml/min), a single peristaltic pump (Pharmacia p-1, Sweden) was used to push the carrier and eluent streams with silicon tube (0.8mm id). Injection valve six-way (Rhyodyne, USA) and two switching valves six-way (Rhyodyne, Model 7000, USA) were purchased from the United States. The luminol and peroxide reagents are combined at a Y-piece which was attached directly to a glass helical flow cell placed next to the detector's optical window (Cecil CE303 grating spectrophotometer), the light source was blocked. The blue light was recorded by a digital multimeter (Victor 70c), and signals were measured automatically as peak heights. Data treatment was implemented in an Excel spreadsheet by random 9922.

Reagents

Dissolving 10.599 g of Na_2CO_3 in 1L of deionized water to make a sodium carbonate solution (0.1 M) to prepare luminol solution.

0.1M) Of Hydrogen peroxide solution was prepared by diluting 8.596 ml of 35% H_2O_2 to 1L of deionized water.

Approximately (1mM) of Luminol solution was prepared by weighing 0.1771 g of luminol in 1000 mL of 0.1 M Na_2CO_3 .

(0.4M) Sodium bromide solution weights 20.57 g of NaBr and dissolved in 0.5L of deionized water.

Potassium Bromate solution ;(108 mg/L), dissolve 0.108g of KBrO_3 in 1L of deionized water.

Hydrochloric acid solution; (1M), dilute 41.42 ml of pure %37 Hydrochloric acid to 0.5L of deionized water.

Magnesium chloride heptahydrate solution; (0.5M), dissolve 11g of $\text{MgCl}_2 \cdot 7\text{H}_2\text{O}$ in 100 ml of deionized water.

A strong anion exchanger Dowex® 1X4, chloride form (Sigma-Aldrich, Germany), was used to prepare both (Cl^- , and BrO_3^-) mini-columns.

Interfering solutions ;(1000 mg/L) of each NaIO_3 , KNO_2 , NaBr, KClO_3 , KClO_4 , KF, K_2SO_4 , KNO_3 , $\text{Ca}(\text{ClO})_2$, NaCl, $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ and $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ were prepared .

All standard stock solutions were directly stored at four °C in a refrigerator[36]. To prepare working

solution diluting the standard solution with deionized water before using it daily.

Sample preparation

The total of four natural mineral, bottled water samples (sterilized by RO and Ozone) with different brands were collected from Kurdistan (north of Iraq) markets in January 2021. The samples were kept at room temperature. Before injection, the sample treating with The Dionex OnGuard II Ba, Ag, and H (1cm^3) separately at a flow rate of $0.5\text{ml}/\text{min}$. Flush the cartridge with the appropriate amount of deionized water before using it. The 9.8 mL of water samples were spiked with $100\mu\text{L}$ of each solution of 0.5M magnesium chloride ($\text{MgCl}_2 \cdot 7\text{H}_2\text{O}$) and 0.167M sodium carbonate. Discard 3 ml of the initial sample waste volume and collect the remaining volume until injection.

Preparation of the columns

The chloride form strong anion-exchange resin (Dowex IX4, 200-400 mesh) was used as Cl^- form and a portion was transformed to bromate forms. Two gram of resin was weighed and immersed in a hundred millilitres of two round-bottomed flasks, which contained deionized water and potassium bromate solution, respectively as detailed by Azad T. Faizullah described[34]. The baseline was stabilized by passing deionized water through the ion exchanger column for several minutes and was then kept in this condition until use.

Flow injection analysis instrumentation

Figure 1 illustrates a schematic representation of the (OMAFIA-CL) manifold. The manifold enables exchanging of ions, amplification process, elution, regeneration of resin, formation of bromine, and finally, the reaction of Br_2 with luminol/ H_2O_2 stream to produce CL light. All contribute to the success of the amplification and detection of bromate. A six plungers pump was used to push the carrier and eluent streams. Their flow rate is measured to be ($1\text{ ml}/\text{min}$) until the end of the amplification process. Then during the elution process, the flow rate was changed to ($3\text{ ml}/\text{min}$). The loop of the six-way injection valve was filled with $500\mu\text{L}$ of standard solutions of KBrO_3 pushed into the carrier stream of deionized water then passed it through both (4 cm glass tube, 5mm i.d) chloride exchange (Dowex® IX4) and BrO_3^- form columns. The bromate column is directly connected with the fourth path of

switching valve 1 to support flow during the amplification process. Two six-way switching valves and a (3- way) valve were applied to interchange the path of flow and the switching flow of the carrier during the amplification and elution process. The procedure involved the following steps:

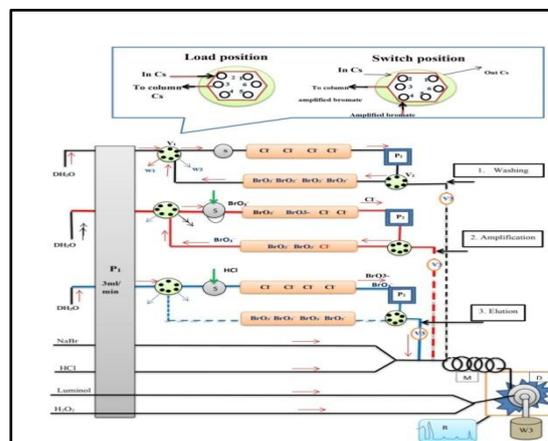


Fig.1. The OMAFIA-CL manifold for the online monitoring amplification reaction, the (V1) and (V2) are switching 6-way valves to exchange path of flow. (V3) is 3-way Hamilton valve to control flow path between washing and elution process. (s) Is the sample injected through injection valve. (w 1, 2, 3) are waste, (p1) is Peristaltic pump 6- plunger. (p2) Single channels peristaltic pump. (Cl^- and BrO_3^-) are two mini- anion exchange columns (4cm). (DH_2O) is double distilled deionized water. (M) Is a mixing coil. (D) Is a detector. (R) Is a recorder. (HCl) is hydrochloric acid. (NaBr) is a sodium bromide solution. Luminol and peroxide (H_2O_2) are streams. The black line is washing the system process of online monitoring amplification. The red line is an amplification process. The blue line is the elution and regeneration steps of amplified anion by suitable eluent of hydrochloric acid. The dotted line illustrates the interruption of the flow in that position. The Red arrow illustrates the path of flow in that position. The double black arrow means ready for elution.

Washing the manifold

The black path of figure 1 displays that deionized water (or washing solution) is cycling through the manifold and detector. A key –valve (V1) used to start with load position so that, the deionized water flows through the Cl^- - form resin, the BrO_3^- form

resin (using – Pump 2, key valve 2 , the 4th position key-switching valve (V1) then to waste (W1-5th position), and the key valve (V3) is turned to the elution path(load position). Meanwhile, the calibration solution continuously flowed through the detector.

Amplification

The red line of figure 1 clear that; after filling the path up with deionized water, the Switching valve (V1) was turning into switch position while V2 and V3 remained stable in the load position, so that the cycle line was closed and the washing Solution was directed to waste (W2,1st position). The Amplification was started by injecting the sample (BrO_3^- solution) at a precise time (upon injection valve). It was found that under optimum conditions, the amount of time it takes for the sample solution to pass through both columns and return to the Cl^- form resin column is about 30 seconds which could be regarded as one cycle. This can be applied for amplifying the bromate anion sample as follows: During that time (30 sec), the injected BrO_3^- displace with an equivalence amount of Cl^- anions, and Cl^- replaced with the amount of anion of BrO_3^- Which

passes valve (V1) to accumulate at the Cl^- form resin. Accordingly, the injected BrO_3^- was doubled, so this one cycle of amplification was completed. Completely three cycles about of 90 seconds were enough to amplify bromate under optimum condition. While the amplification was in progress, it was necessary to fill the loop of the injection valve (VS) so that the eluent of HCl was ready for Elution.

Elution

The blue path of figure 1 shows that Elution of amplified species was achieved rapidly by instantly turning valves (V1, V2, V3, and VS) to their alternative positions. Thus, the system was allowed the HCl eluent to desorb the anions of BrO_3^- deposited in the Cl^- form resin to the confluence point of sodium bromide and acid media ,after merging streams at confluence point, bromine was produced, which then catalyzed (peroxide/Luminol) to produce CL blue light. The operation of valves was shown in table 1. The repositioning of the manifold to the washing state is achieved by turning valves (V1, V2, V3 and Vs) to their initial positions. Steps 2.5 (1, 2, and 3) were repeated for each amplification process

Table 1. Protocol sequences of OMAFIA-CL for the position of valves.

steps	Condition	Valve position *				Flow rate ** (ml/min)		Time
		V1	V2	V3	VS			
						P1	P2	
1	Washing	L	L	L	L	3	3	15-25(min)
2	Amplification	S	L	L	I _A	1	1	30s (1 cycle) 30*3=90 s
3	Elution	L	S	S	I _E	3	3	30s(peak)

* Represents for position of valves as follow: L (load) , S(switch), IA(injection of analyte),and IE(injection of eluent).

** Represents the speed of flow from peristaltic pump 1 and 2 .

Regeneration of the ion-exchange columns

The Cl^- form resin column is automatically regenerated during each elution process by passing 100 μl of (0.5M) hydrochloric acid. The most of BrO_3^- -form resin is converted to Cl^- form resin during the amplification process, could simply be regenerated by passing a solution of potassium bromate for the desired length of time. Then the stream was changed to deionized water again, so that the manifold returned to its washing position again.

Ion chromatography method

The ozonized drinking water testing was performed by using Ion Chromatograph under the following requirements:

Column: Shodex IC SI-52-4E, Column temperature: 45°C, Flow rate: 0.8 ml min⁻¹, Eluent: 3.6 mM Na_2CO_3 , Detector: Suppressed conductivity, Sample volume: 50 μl , Retention time of Bromate: 8 min.

3. Result and discussion

Chemical parameters optimization

Acidic media and sodium bromide concentration

During the investigation, hydrochloric acid (HCl) from concentration range (0-0.9M) was employed, and it was made using the serial dilution method from standard solution to 50ml of deionized water. The best acidic media for generating bromine was discovered to be (0.1M) HCl. Furthermore, hydrochloric concentrations from (0.1-0.55M) were used as an eluent to desorb all of the amplified anions of bromate on the first column of (Cl⁻) form column. When the concentration of the eluent (HCl) was increased, maximum intensity in the form of peak position was obtained at (0.5 M). Figure 2 displays the peak of Chemiluminescence variation in (mV). The concentration of sodium bromide was adjusted from 0 to 0.35 M when the other variables remained fixed. According to the results given in Figure 2, raising the concentration of Br⁻ ions leads to a rise in the emission light intensity (mV) in the system. As a result, 0.1 M was chosen as the optimal concentration.

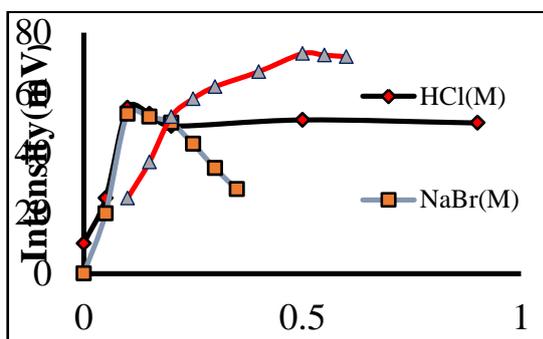


Fig.2. Effect of the chemical concentration of Hydrochloric acid, and Sodium bromide on peak high (mV).

The concentration of hydrogen peroxide

The influence of H₂O₂ concentration on Chemiluminescence intensity and system sensitivity in the range (1-30mM) was monitored, and the data are shown in Figure 3. When the concentration of H₂O₂ was increased, the intensity in the shape of peak height reached its maximum at (10m M).

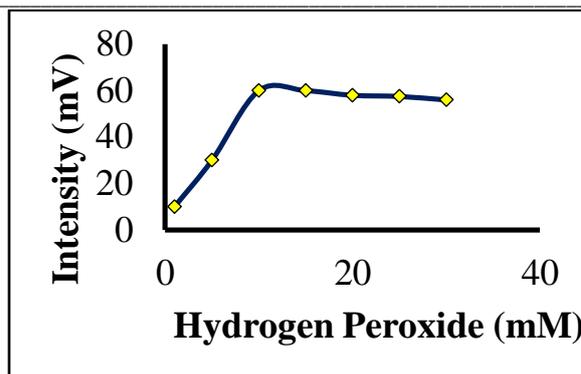


Fig.3. Influence of Hydrogen Peroxide concentration on light intensity for bromate determination.

The concentration of Luminol

The effect of varied luminol solution concentrations ranged from (1.*10⁻⁵–to 3.*10⁻⁴) M. Thus, the peak signal high was maximal and reproducible (mV). The data in Figure 4 show that increasing the luminol concentration raised the intensity of the CL light until the system achieved its maximum power concerning luminol concentration (1.*10⁻⁴ M) and thereafter gradually decreased.

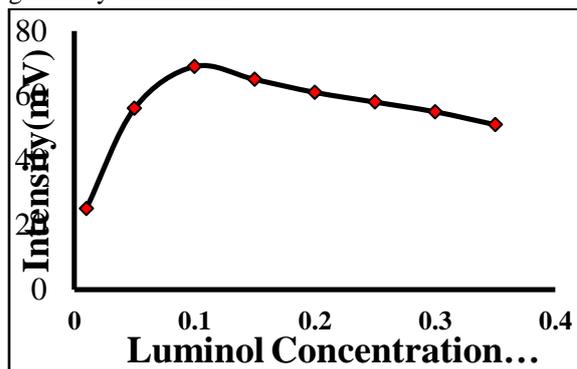


Fig.4. The Influence Luminol concentration on intensity of bromate.

Optimization of physical parameters.

The effect of Flow rate, Length of columns, Cycle number

Figure 5 depicts a variety of physical variables, such as the effect of the speed pumps of P1 and P2 on the CL intensity as peak height (mV), which were tested over the ranges of (0.5-5.0) ml/min and (1-5) ml/min, respectively, inside columns during the amplification and elution processes. A high flow rate increases the intensity of the chemiluminescence but decreases the efficiency of the anion-exchange columns. Hence two flow rates are used during the

operation. A 1 ml/min flow rate was chosen as the optimum flow rate inside both columns. Low flow rate delayed reaction between exchangeable anions[37-39]. Furthermore, high flow rates cause tube breakage, resulting in a drop in intensity due to an analyte loss. A flow rate of 3ml/min was followed by amplification to elute bromate desorption and detection. Figure 5 shows that raising the column length from 2 to 8 cm enhances the intensity of the light and has no effect when lengthened to 8 cm. A more extended column, in general, enhances separation. This could be because a sufficient equal amount of exchangeable ions occurred. As a result, 4cm was chosen for additional testing. On the other

Fig. 1. The effect of physical variables on Online monitoring amplification method by FIA-CL

The length of mixing coil and Sample volume

Reacting coil was positioned between flows of sodium bromide and amplified bromate in the acidic media, according to the design of the developed OMAFIA-CL system shown in figure 1. The (0-200 cm) range was tested. Figure 6 depicts the effect of each length. As the coil length increases, the CL intensity increases because more time is available to create Br₂. As a result, the ideal coil length for Br₂ production was chosen to be 100 cm. A sample size of 500 µL was chosen to reduce sample dispersion and respond better. Larger samples, on the other hand, minimize chromatographic efficiency.

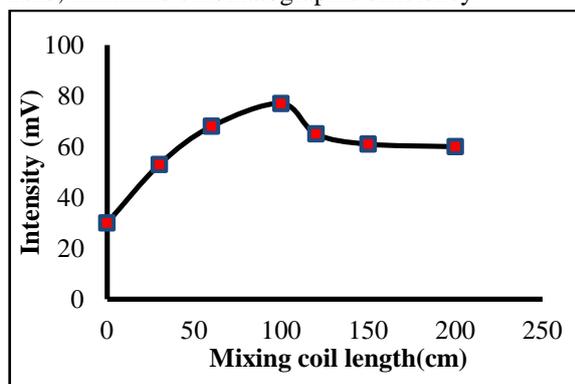
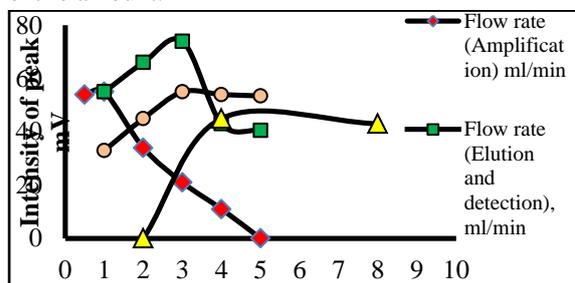


Fig.2. The influence of the mixing coil and sample volume on the intensity of Chemiluminescence light.

Calibration graph

A calibration graph was created by comparing different concentrations in µg/L of bromate stock solutions against changes in CL-intensity in the form of peak height using the OMAFIA-CL system with

hand, for examining cycles, one cycle is insufficient to accumulate all of the analytes of bromates; more than two cycles are required to adsorb all of the bromate. Three cycles were sufficient to absorb the entire amount.



the manifold design shown in Figure 1 and under optimum lab conditions (mV)[40]. Figure 7 shows a linear relationship for the concentration range (5-100 µg/L) with a correlation value $R^2 = 0.9995$. The detection limit was of 3.9µg/L and limit of quantification was 12µg/L. The accuracy and reliability of the present method were measured in terms of relative error (E percent) and relative standard deviation (RSD percent) under optimum experimental parameters for seven replicates at two different bromate concentrations (10 and 80µ g/L) and were (1.34,1.71, and (-1.37, 0.63), respectively.

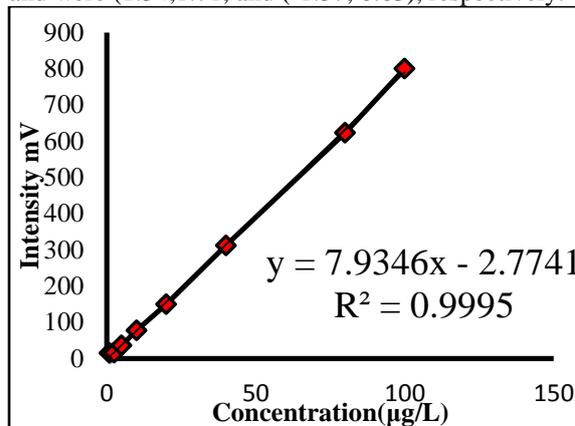


Fig.3. The calibration graph for determination of bromate by OMAFIA-CL method.

Effect of interferences

The study investigated the effects of various concentrations of interfering ions on the standard bromate solution (25µg/L). The permissible concentration of the ion was calculated by measuring the highest concentration at which the reaction change must be less than 5% of the response obtained for a standard bromate solution. Table 2 shows that, the ion exchanger column performance is restricted

by column capacity, which is why ion-exchange competition arises. The resin in the column can only trap a certain amount of an analyte. The trap loses its quantitative nature when the column's capacity is achieved. When ions with extremely varied affinities for the resin are enhanced, the processes become more complex. When high affinity ions listed in table

2 are present in a water sample, bromate recovery decreases. Solid phase extraction (SPE) cartridges comprising various sorbent materials were used to solve the problem. Dionex On Guard II Ba/Ag/H (1cm³) separately was utilized to reduce interferences, as indicated in section 2.3 above[41].

Table 2. The effect of different interfering ions on OMAFIA-CL method.

Substances	Tolerable concentration(mg/L)with (25µg/ L) of the standard solution of bromate
NaCl	5 ^a ,100 ^b
NaBr	0.5 ^a ,80 ^b
K ₂ SO ₄	2 ^a ,100 ^b
KF	15 ^{a*}
KNO ₂	8 ^a ,8 ^b
KNO ₃	25 ^a ,24 ^b
KClO ₃	20 ^a ,20 ^b
Ca(ClO) ₂	5 ^a ,5 ^b
KIO ₃	10 ^{a*}
CuCl ₂ .2H ₂ O	8 ^a ,25 ^b
Cd(NO ₃) ₂ .4H ₂ O	10 ^a ,70 ^b
Cr(NO ₃) ₃ .9H ₂ O	6 ^a ,35 ^b
COCl ₂ .6H ₂ O	3 ^a ,45 ^b

^a Represents the method of tolerable concentration without passing through Dionex onguard.

^b Real sample pretreatment with Dionex OnGuard II Ba, Dionex OnGuard II Ag, and Dionex OnGuard II H.(The sample was spiked with 100 µL of 0.5M magnesium chloride solution and 100 µL of 0.167M sodium carbonate solution.

* Represents to not investigated.

Application

The amplification approach was used to analyze ozonated mineral water samples successfully. Anions such as chloride and sulfate, which are present in considerably larger concentrations in bottled water, can operate as a bromate replacement during the ion exchange in both columns. Water samples were treated with the OnGuard columns before injection to

reduce effect of influence. Table 3 summarizes the analytical findings. It is clear that adding 25 µg /L of standard solution of bromate to the real samples yielded in recoveries ranging from 99 to 102 percent. Bromate levels in bottled water samples were lower than the maximum allowable bromate level in drinking water (10 µg L⁻¹). The samples evaluated using OMAFIA and IC techniques were safe to drink.

Table 3. OMAFIA-CL method for determination of BrO₃⁻ in ozonized drinking water (n=5).

Sample of water	OMAFIA detection Found(µg L ⁻¹)	Spiked (µg/L)	Recoverd (µg/L)	Recovery (%)	IC detection Found(µg/L)
Sample 1	N.D*	25	25.68	102.72	N.A*
Sample 2	4.5	25	29.33	99.3	4.1
Sample 3	5.6	25	30.47	99.48	5
Sample 4	4.3	25	29.33	99.74	N.A

*N.D represents not detected, and N.A represents not applied.

4. Conclusion

The OMAFIA-CL method was utilized successfully to determine bromate in ozonated mineral water over a concentration range of 5–100 µg/L, with the LOD being 3.9 µg/L, which was lower than the USPEA and WHO standard limit. The process is easily repeatable. The coefficient of variation at the bromate concentrations studied does

not exceed 1.7 percent across all measurements. The reaction of BrO₃⁻ - Br⁻ - H₃O⁺ makes the release of bromine, the absence of any of these three ions results in a zero baseline. Because there is no metal to accelerate the reaction, the luminol luminescence does not create any light, causing the detector response to be zero. The OMAFIA-CL methodology can be recommended as a reliable screening tool for

finding trace ions. The automatic amplification technique provided for bromate determination using two mini-columns anion exchange resin has some advantages, including increased sensitivity as well as amplification of bromate analyte after sufficient cycling across both columns. Additionally, advantages include simplicity, low cost, and reduced reagent consumption. The methodology is more stable since the concentration of procedure reagents may be used to check column capacity. Chloride and sulfate anions were detected in bottled water at molar values, many times higher than bromate. Affinity anions to desorb anion with the same charge in columns and reagent sensitivity are two major effects of interferences. The interferences in real samples were eliminated by using Dionex Ongaard II Ba, Ag, and H cartilage before injection. Ions, Cobalt, chrome, copper, chlorite, nitrite, nitrate, fluoride, and iodate at levels seen in bottled water cannot interfere with bromate detection. More studies on the technology will be carried out by using the OMAFIA-CL method to determine trace amounts of ions that are difficult to detect.

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6. References

- [1] Bonacquisti TP. A drinking water utility's perspective on bromide, bromate, and ozonation. *Toxicology* 2006;221:145-8.
- [2] West DM, Mu R, Gamagedara S, Ma Y, Adams C, Eichholz T, et al. Simultaneous detection of perchlorate and bromate using rapid high-performance ion exchange chromatography-tandem mass spectrometry and perchlorate removal in drinking water. *Environmental Science and Pollution Research* 2015;22:8594-602.
- [3] Organization WH. Guidelines for drinking-water quality: first addendum to the fourth edition. 2017.
- [4] Fawell J, Walker M. Approaches to determining regulatory values for carcinogens with particular reference to bromate. *Toxicology* 2006;221:149-53.
- [5] Zhang X, Guo L, Zhang D, Ge X, Ye J, Chu Q. Sensitive determination of bromate in water samples by capillary electrophoresis coupled with electromembrane extraction. *Food analytical methods* 2016;9:393-400.
- [6] Von Gunten U, Oliveras Y. Advanced oxidation of bromide-containing waters: bromate formation mechanisms. *Environmental science & technology* 1998;32:63-70.
- [7] Hautman DP, Munch DJ, Frebis C, Wagner HP, Pepich BV. Review of the methods of the US Environmental Protection Agency for bromate determination and validation of Method 317.0 for disinfection by-product anions and low-level bromate. *Journal of Chromatography A* 2001;920:221-9.
- [8] Weinberg HS, Yamada H. Post-ion-chromatography derivatization for the determination of oxyhalides at sub-PPB levels in drinking water. *Analytical chemistry* 1998;70:1-6.
- [9] Snyder SA, Vanderford BJ, Rexing DJ. Trace analysis of bromate, chlorate, iodate, and perchlorate in natural and bottled waters. *Environmental science & technology* 2005;39:4586-93.
- [10] Mittrakas M. Bromate determination in water using chlorpromazine after correction of chlorinating agents and humic substances interference. *Journal of Analytical Chemistry* 2007;62:1055-63.
- [11] Ketai W, Huitao L, Jian H, Xingguo C, Zhide H. Determination of bromate in bread additives and flours by flow injection analysis. *Food chemistry* 2000;70:509-14.
- [12] Gordon G, Bubnis B, Sweetin D, Kuo C-y. A flow injection, non-ion chromatographic method for measuring low level bromate ion in ozone treated waters. 1994.
- [13] Oliveira SM, Segundo MA, Rangel AO, Lima JL, Cerda V. Spectrophotometric determination of bromate in water using multisyringe flow injection analysis. *Analytical letters* 2011;44:284-97.
- [14] Farrell S, Joa J, Pacey GE. Spectrophotometric determination of bromate ions using

- phenothiazines. *Analytica chimica acta* 1995;313:121-9.
- [15] Yokota A, Kubota H, Komiya S, Sato K, Akiyama H, Koshiishi I. Sensitive and simple determination of bromate in foods disinfected with hypochlorite reagents using high performance liquid chromatography with post-column derivatization. *Journal of Chromatography A* 2012;1262:219-22.
- [16] Arias F, Li L, Huggins TG, Keller PR, Suchanek PM, Wehmeyer KR. Trace analysis of bromate in potato snacks using high-performance liquid chromatography– tandem mass spectrometry. *Journal of agricultural and food chemistry* 2010;58:8134-8.
- [17] Shi Y, Liang L, Cai Y, Mou S. Determination of trace levels of bromate in flour and related foods by ion chromatography. *Journal of agricultural and food chemistry* 2006;54:5217-9.
- [18] Aggrawal M, Rohrer JS. Selective and sensitive determination of bromate in bread by ion chromatography-mass spectrometry. *Journal of Chromatography A* 2020;1615:460765.
- [19] Joyce RJ, Dhillon HS. Trace level determination of bromate in ozonated drinking water using ion chromatography. *Journal of Chromatography A* 1994;671:165-71.
- [20] Zhang X, Saini C, Pohl C, Liu Y. Fast determination of nine haloacetic acids, bromate and dalapon in drinking water samples using ion chromatography–electrospray tandem mass spectrometry. *Journal of Chromatography A* 2020;1621:461052.
- [21] Echigo S, Minear RA, Yamada H, Jackson PE. Comparison of three post-column reaction methods for the analysis of bromate and nitrite in drinking water. *Journal of chromatography A* 2001;920:205-11.
- [22] Urbansky ET, Brown SK. Influence of reagent purity on the ion chromatographic determination of bromate in water using 3, 3'-dimethoxybenzidine as a prochromophore for photometric detection. This is the work of United States government employees engaged in their official duties. As such it is in the public domain and exempt from copyright. © US government. *Journal of Environmental Monitoring* 2000;2:571-5.
- [23] Shi H, Adams C. Rapid IC–ICP/MS method for simultaneous analysis of iodoacetic acids, bromoacetic acids, bromate, and other related halogenated compounds in water. *Talanta* 2009;79:523-7.
- [24] Cai Q, Guo Z-X, Yu C, Zhang W, Yang Z. Bromate assay in water by inductively coupled plasma mass spectrometry combined with solid-phase extraction cartridges. *Analytical and bioanalytical chemistry* 2003;377:740-8.
- [25] Liu M, Lin Z, Lin J-M. A review on applications of chemiluminescence detection in food analysis. *Analytica Chimica Acta* 2010;670:1-10.
- [26] Ayoob, A., Sadeek, G., Saleh, M. (2022). Synthesis and Biologically Activity of Novel 2-Chloro -3-Formyl -1,5-Naphthyridine Chalcone Derivatives. *Journal of Chemical Health Risks*, 12(1), 73-79. doi: 10.22034/jchr.2022.688560
- [27] Ruqaya M. Hamid Al-Sultan, Ammar Abdulsalaam Al-Sultan, Mohammed A. Hayawi, Bilal J M Aldahham, Mohanad Y. Saleh, Hazim A. Mohammed. The effect of subclinical thyroid dysfunction on B- type natriuretic peptide level. *Revis Bionatura* 2022;7(2) 21. <http://dx.doi.org/10.21931/RB/2022.07.02.21>
- [28] Yan Z, Zhang Z, Yu Y, Liu Z, Chen J. Chemiluminescence determination of potassium bromate in flour based on flow injection analysis. *Food chemistry* 2016;190:20-4.
- [29] Satienerakul S, Phongdong P, Liawruangrath S. Pervaporation flow injection analysis for the determination of sulphite in food samples utilising potassium permanganate–rhodamine B chemiluminescence detection. *Food chemistry* 2010;121:893-8.
- [30] Hamdoon, A., Al-Iraqi, M., Saleh, M. (2022). Synthesis of Some Multi-cyclic Sulfhydryl Donor Compounds Containing 1,2-dithiol-3-thione moiety. *Egyptian Journal of Chemistry*, 65(3), 427-434. doi: 10.21608/ejchem.2021.93344.4408
- [31] Ali DS, Faizullah AT. Combination of FIA-CL Technique with ion-exchanger for determination of sulphate in various water resources in Erbil City. *Arabian Journal of Chemistry* 2012;5:147-53.
- [32] Shakir IM, Faizullah AT. Determination of bromide using flow injection and chemiluminescence detection. *Analyst* 1989;114:951-4.

- [33] Saeed, Z., Saleh, M., sadeek, G. (2022). Synthesis and Biological Evolution of Novel Substituted 1,2,4-triazine from Sulfanilic Acid. *Egyptian Journal of Chemistry*, (), -. doi: 10.21608/ejchem.2022.132916.5870
- [34] Weisz H, Fritsche U. Einige neue Möglichkeiten zur Durchführung zyklischer Vervielfachungen. *Microchimica Acta* 1973;61:361-72.
- [35] Hamdoon, A., Saleh, M., Saied, S. (2022). Synthesis & Biological Evaluation of Novel Series of Benzo[f]indazole Derivatives. *Egyptian Journal of Chemistry*, (), -. doi: 10.21608/ejchem.2022.120818.5418
- [36] Ali, R. T., Al-Niemi, K. I., & Mohammedthalji, N. H. (2021). A practical and theoretical study of the mechanical kinetics of ascorbic acid adsorption on a new clay surface. *Egyptian Journal of Chemistry*, 64(8), 4569-4581.
- [37] Faizullah AT, Townshend A. Applications of ion-exchange minicolumns in a flow-injection system for the spectrophotometric determination of anions. *Analytica Chimica Acta* 1986;179:233-44.
- [38] Uraisin K, Takayanagi T, Nacapricha D, Motomizu S. Novel oxidation reaction of prochlorperazine with bromate in the presence of synergistic activators and its application to trace determination by flow injection/spectrophotometric method. *Analytica chimica acta* 2006;580:68-74.
- [39] Toohi, H. T. A. S., Rabeea, M. A., Abdullah, J. A., & Muslim, R. F. (2021). Synthesis and characterization activated carbon using a mix (asphalt-polypropylene waste) for novel azo dye (HNDA) adsorption. *Carbon Letters*, 31(5), 837-849.
- [40] Al-Thakafy, N., Al-Enizzi, M., Saleh, M. (2022). Synthesis of new Organic reagent by Vilsmeier – Haack reaction and estimation of pharmaceutical compounds (Mesalazine) containing aromatic amine groups. *Egyptian Journal of Chemistry*, 65(6), 685-697. doi: 10.21608/ejchem.2021.101851.4729
- [41] Mohammedthalji, N., Ali, R., Saied, S. (2022). Thermodynamic & Kinetic Study of the Adsorption of Glycolic acid using a Natural Adsorbent. *Egyptian Journal of Chemistry*, 65(6), 505-520. doi: 10.21608/ejchem.2022.119362.5365