Application Note AN-M-015

Trace haloacetic acids, dalapon, and bromate measurement in drinking water

Robust analysis with IC-MS/MS according to US EPA 557

Chlorinating drinking water helps reduce pathogens, but it can also form potentially carcinogenic byproducts, e.g., haloacetic acids (HAAs), dalapon, and bromate [1,2]. The US Environmental Protection Agency (EPA) and the EU set a maximum contamination limit for the sum of five HAAs (HAA5: MCAA, MBAA, DCAA, DBAA, TCAA) of 60 parts per billion (60 µg/L) [3]. EPA Method 557 describes their quantification in the µg/L range in a wide variety of water types [4]. Here, the analysis is accomplished with a Metrohm ion chromatograph (IC) coupled to a triple quadrupole Agilent mass spectrometer (MS). This sensitive method requires no sample extraction, and the Metrohm Suppressor Module eliminates any eluent interferences. Analytes are well-resolved from matrix components with the Metrosep A Supp 19 column. Matrix spike recoveries for 1 µg/L of all analytes were between 65–115% even in heavily loaded water samples. Minimum reporting levels (MRL) were 0.025–0.25 µg/L. The presented IC-MS/MS method fulfills all requirements of EPA Method 557.

SAMPLE AND SAMPLE PREPARATION

Water samples included tap water (from eastern Switzerland) and mineral water (Evian containing c(hydrogen carbonate) = 360 mg/L, c(sulfate) = 14 mg/L, c(chloride) = 10 mg/L, and c(nitrate) = 3.8 mg/L). Additionally, the laboratory synthetic sample matrix (LSSM) according to EPA 557 (c(ammonium chloride) = 100 mg/L, c(nitrate) = 20 mg/L, c(hydrogen carbonate) = 150 mg/L, c(chloride) = 250 mg/L, and c(sulfate) = 250 mg/L) was analyzed. Samples were stabilized with 0.1% methanol (v/v) and cooled to 4 °C. Internal standards were added at a concentration of 4 µg/L (here: MCAA-^{13}C and MBA-^{13}C).

EXPERIMENTAL

The hyphenation of HPLC with mass spectrometry has commonly focused on the study of organic molecules. Hyphenating ion chromatography (IC) with mass spectrometry (MS) opens up the field to highly sensitive analysis of ionic and more polar substances in aqueous solutions or salt-containing matrices. Using the 889 IC Sample Center – cool guarantees stable and reproducible sample processing at 4 °C (**Figure 1**) by preventing the decay of the degradation-sensitive HAAs.

Figure 1. Instrumental setup to measure haloacetic acids, dalapon, and bromate including an 889 IC Sample Center – cool (Metrohm), 940 Professional IC Vario (Metrohm), and 6475 Triple Quadrupole LC/MS with Jet Stream Technology Ion Source (Agilent). A Dosino was used for direct infusion to the MS during method optimization.

The metal-free microbore ion chromatograph 940 Professional IC Vario with a Metrosep A Supp 19 column, sequential suppression, and an IC Conductivity Detector MB accomplished chromatographic separation without any interferences and a reduced void volume. Sensitive and selective detection of haloacetic acids was carried out with an Agilent 6475 Triple Quadrupole LC/MS equipped with an Agilent Jet Stream Technology Ion Source, operated in dynamic multiple reaction monitoring (dMRM) acquisition mode. Conductivity detection can be used to quantify common anions like fluoride, chloride, nitrate, or sulfate in parallel. An additional Dosino enables direct infusion of standard solutions to the MS for method optimization, i.e., finding the best MS parameters to detect the analytes of interest.

The 948 Continuous IC Module, CEP precisely produces a potassium hydroxide eluent in concentrations from 15–100 mmol/L potassium hydroxide (KOH) (**Figure 2**). The IC was operated with the software MagIC Net, and the MS by MassHunter software. Synchronization of both instruments was controlled via a remote cable. **Table 1** lists the most important instrument settings.

Figure 2. The 948 Continuous IC Module, CEP automatically produces KOH eluent from ultrapure water and a KOH concentrate. The electrochemical eluent production takes place at a membrane in the eluent producer cartridge.

Table 1. This table lists the most important method parameters for haloacetic acid determination with IC-MS/MS.

IC Column	Metrosep A Supp 19 - 150/4.0
Eluent/gradient	15 – 100 mmol/L KOH + 10% methanol
Flow rate	0.5 mL/min
Column temperature	15 °C
Injection volume	100 µL
Suppression	sequential
Ion polarity	negative
Gas flow	12 L/min
Sheath gas flow	12 L/min
Gas temperature	150 °C
Sheath gas temperature	245 °C
Detection	dMRM (dynamic Multiple Reaction Monitoring)

RESULTS

The presented method is capable of determining all relevant haloacetic acids, bromate, and dalapon in drinking water according to EPA 557 (**Table 2**). Separation on the column Metrosep A Supp 19 - 150/4.0 with a hydroxide eluent was robust and reproducible. This combination enabled sufficient resolution between highly concentrated matrix peaks (i.e., chloride, nitrate, bicarbonate, and sulfate) and the analytes (**Figure 3**). The matrix was diverted to the waste to avoid ion suppression in the MS. A further advantage of this setup is the solvent-stable suppressor. Using 10% methanol in the eluent helps the transfer from aqueous to gas phase and has no impact on the suppressor. Thus, no further post-column addition of organic solvents with a secondary pump was necessary to improve evaporation of analytes in the MS.

Calibration from 0.1 – 40 µg/L with quadratic fits resulted in R^2 values in the range of 0.996 – 0.999. Determination of the lowest concentration minimum reporting levels (LCMRL) was done as per EPA 557, chapter 9.2.4 (**Table 2**). Seven replicates were successfully analyzed for the upper and lower PIR (prediction interval of results) limit (acceptable range 50–150%).

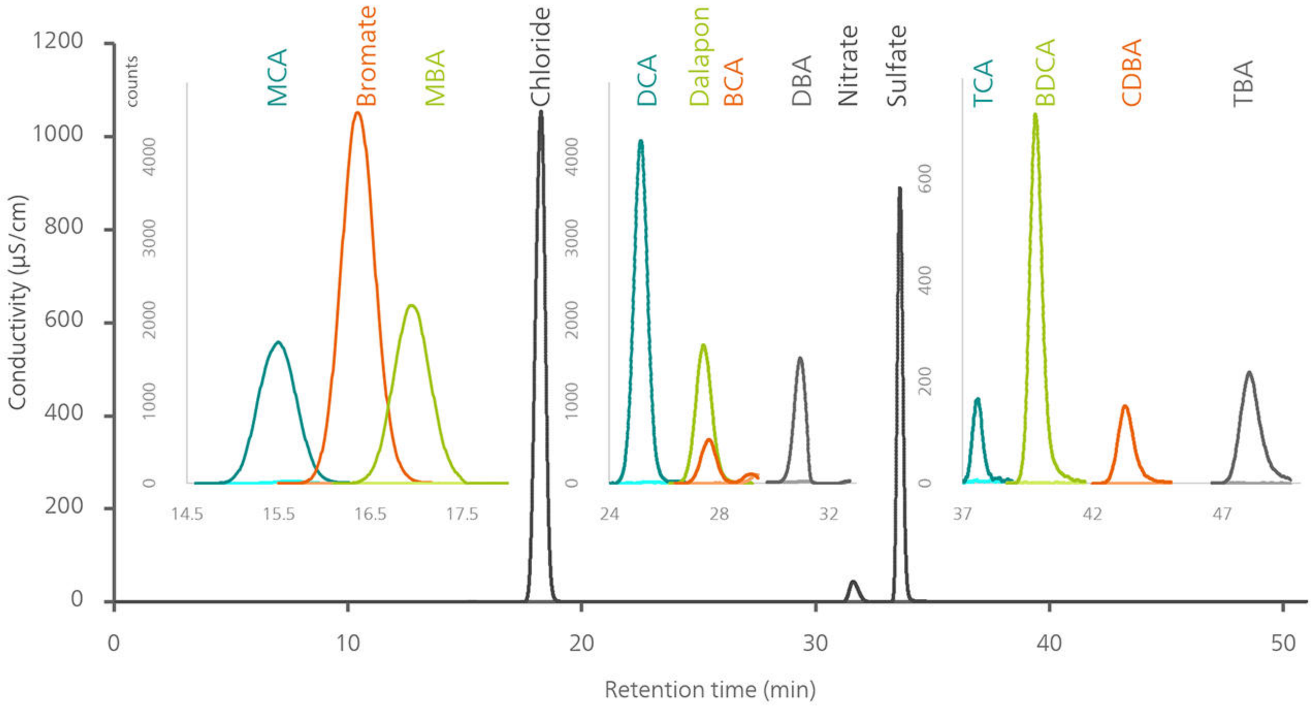

Figure 3. Overlay of a chromatogram of laboratory synthetic sample matrix (LSSM) according to EPA 557 with c(ammonium chloride) = 100 mg/L, c(nitrate) = 20 mg/L, c(hydrogen carbonate) = 150 mg/L, c(chloride) = 250 mg/L, and c(sulfate) = 250 mg/L (light colored lines), and of LSSM spiked with 1 µg/L of all analytes (intensely colored lines). Injection volume was 100 µL.

Water samples were directly analyzed (no dilution needed). **Table 3** shows that spiking recoveries of 1 µg/L were in the range of 65 – 115% (for LSSM), 46 – 112% (for tap water), and 87 – 150% (for Evian water). Replicates for tap water (n = 7) were in the range of 0.7 – 6.8% RSD (relative standard deviation). For mineral water (Evian) (n = 6) and for LSSM (n = 7) RSD values were in the range of 1.6 – 6.3% and 1.0 – 36.5%, respectively. Most values were 5%, except for TCAA (which elutes close to sulfate). Critical pairs were DBA/nitrate and TCAA/sulfate. The diverter windows must be accurately set to acquire complete data for the analytes DBAA and TCAA and divert both nitrate and sulfate to the waste. Sample degradation at room temperature was visible after one day and considerable degradation occurred after four to five days. The samples must be measured in a timely manner or a sampler with cooling function must be used (e.g., 889 IC Sample Center – cool). A Metrohm CO_2-suppressor (MCS) was used in this setup as it improved the conductivity background and hence reduced the number of interfering ions in the MS.

Table 2. Determination of lowest concentration minimum reporting levels (LCMRL) was done as per EPA 557, chapter 9.2.4 minimum reporting level (MRL) confirmation. Seven replicates were analyzed for the upper and lower PIR (prediction interval of results) limit (acceptable range 50 – 150%). *Concentrations lower than 0.025 µg/L were not tested, but signal-to-noise ratio was >10 and showed that the minimum limit was not reached.

Analyte	Abbreviation	Retention time [min]	Precursor *m/z*	Product *m/z*	Concentration for minimum reporting level [µg/L]	PIR limits [%]
Monochloroacetic acid	MCAA	15.8	93	34.9	0.025*	91 – 109
Monobromoacetic acid	MBAA	17.2	137	79	0.025*	88 – 112
Bromate	BrO_3	16.7	127	111	0.025*	84 – 116
Dichloroacetic acid	DCAA	25.6	127	83	0.025	84 – 116
Dalapon	DAL	28.0	141	97	0.025	74 – 126
Bromochloroacetic acid	BCAA	28.0	173	81	0.05	74 – 126
Dibromoacetic acid	DBAA	31.4	217	173	0.025	75 – 125
Trichloroacetic acid	TCAA	37.9	161	117	0.25	62 – 131
Bromodichloroacetic acid	BDCAA	40.2	163	81	0.025	79 – 121
Chlorodibromoacetic acid	CDBAA	43.5	207	79	0.025	52 – 148
Tribromoacetic acid	TBAA	49.1	251	79	0.025	62 – 138

Table 3. Three types of water samples were spiked with 1 µg/L of all listed analytes and determined with IC-MS/MS. Analytes were not evaluated in the original unspiked samples. They were either not detected or below 0.1 µg/L. Concentration values are averaged over at least six replicates.

Analyte	Concentration [µg/L] in samples spiked with 1 µg/L of all analytes		
	Tap water (eastern Switzerland)	Mineral water (Evian)	LSSM (EPA 557)
MCAA	1.12	1.41	1.15
MBAA	1.00	0.97	0.87
BrO_3^-	0.88	0.86	0.84
DCAA	0.88	1.03	0.80
DAL	0.88	0.93	0.76
BCAA	0.87	0.87	0.71
DBAA	0.88	1.22	0.79
TCAA	0.46	1.50	0.65
BDCAA	0.89	0.91	0.87
CDBAA	0.88	1.00	0.88
TBAA	0.88	1.43	0.84

CONCLUSION

The presented method fulfills all analytical requirements of US EPA 557 [4]. The robust setup of hyphenating Metrohm IC and Agilent MS guarantees the highest sensitivity and selectivity for all relevant haloacetic acids, dalapon, and bromate, even in complex drinking water matrices. The five representative substances (mono-, di-, and trichloroacetic acid, and mono- and dibromoacetic acid) were precisely quantified in the sub µg/L concentration range for various water samples. The requirements of EPA 557 [4] and the EU directive [5] are met with this method.

REFERENCES

1. Zhao, H.; Yang, L.; Li, Y.; et al. Environmental Occurrence and Risk Assessment of Haloacetic Acids in Swimming Pool Water and Drinking Water. *RSC Adv 10* (47), 28267–28276. DOI:10.1039/d0ra02389b
2. Sinha, R.; Gupta, A. K.; Ghosal, P. S. A Review on Trihalomethanes and Haloacetic Acids in Drinking Water: Global Status, Health Impact, Insights of Control and Removal Technologies. *Journal of Environmental Chemical Engineering* **2021**, *9* (6), 106511. DOI:10.1016/j.jece.2021.106511
3. US EPA, O. *National Primary Drinking Water Regulations*. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations (accessed 2022-09-19).
4. United States Environmental Protection Agency. Method 557: Determination of Haloacetic Acids, Bromate, and Dalapon in Drinking Water by Ion Chromatography Electrospray Ionization Tandem Mass Spectrometry (IC-ESI-MS/MS). *EPA Document No. 815-B-09-012* **2009**.
5. *Directive - 2020/2184 - EN - EUR-Lex*. https://eur-lex.europa.eu/eli/dir/2020/2184/oj (accessed 2024-03-11).

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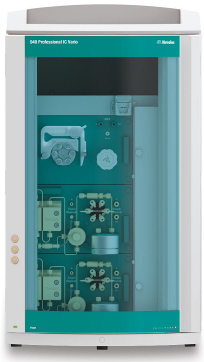
CONFIGURATION



940 Professional IC Vario TWO/SeS/PP/MB

940 Professional IC Vario TWO/SeS/PP は**連続サフレッション**(1チャンネル)とサフレッサー再生のための**ヘリスタリックホンフ**を備えた**2チャンネル**タイフのIC 装置てす。この装置は任意の分離メソットおよび検出メソットによって使用することかてきます。

典型的な使用領域:

- 陰イオンおよび陽イオンの並行測定のための標準装置
- 陰イオンおよび陽イオンのための微量分析
- 陰イオンおよび陽イオンのためのオンラインモニタリンク
- マイクロホア (2mm) アフリケーション向けに最適化、カッフリンク技術 (IC-MS または IC-ICP/MS)に最適

MagIC Net 4.1 以上に対応

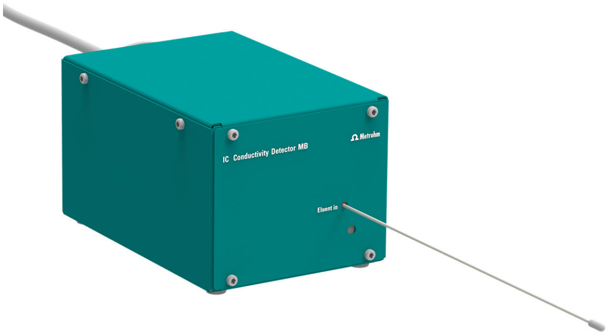
Metrosep A Supp 19 - 150/4.0

卓越した分離特性と高静電容量 – これか、Metrosep A Supp 19 製品群をカラムホートフォリオから明確に際立たせている理由てす。最高のヒーク対称性と選択性、そして高い熱的、機械的、化学的安定性を特徴とし、より高い流速と圧力に対して非常に堅牢て安定したものとなっています。

150 mmのハリエーションは、最も多くの用途を安全に解決し、汎用性か高いため、陰イオンクロマトクラフィーの標準カラムと見なされています。

Metrosep A Supp 19 - 150/4.0 分離カラムは、その高い容量により、要求の厳しいマトリックスを含む複雑な用途にも特に適しています。Metrosep A Supp 19 - 150/4.0 の応用分野は、その優れた分離特性から非常に多岐にわたり、例えは以下のような用途かあります:

- 多種多様な水サンフル中の標準的な陰イオン(フッ化物、塩化物、亜硝酸塩、臭化物、硝酸塩、リン酸塩、硫酸塩)の測定。
- 環境サンフルや食品サンフルなとの複雑なサンフルマトリックス中の標準的な陰イオンと有機酸の測定。
- 発電所の安全な運転を確保するためのホイラー給水中の標準陰イオンと有機酸の測定。
- 医薬品サンフル中の標準的な陰イオンの測定。



IC Conductivity Detector MB

インテリシェントIC装置のためのコンハクトかつインテリシェントな高出力電気伝導度検出器。マイクロホアカラム向けに最適化。優れた温度安定性、保護された検出器フロック内の総合的な信号処理、最新版の DSP (Digital Signal Processing) か高精度の測定を保証します。稼動範囲かタイナミックなのて測定範囲の変更は(自動のものも含めて)不必要てす。

典型的な使用領域:

- 電気伝導度検出器による、化学的サフレッションまたは連続的な化学的サフレッションのある、もしくはサフレッション無しの陰イオンおよひ陽イオンの測定
- マイクロホア (2mm) アフリケーション向けに最適化、カッフリンク技術 (IC-MS または IC-ICP/MS)に最適

仕様概要:

- 0~15000 μS/cm、エリアの切り替えなし
- セル容量: 0.3 μL
- リンク状のステンレス製電極 X2CrNiMo17-12-2 (316 L)、MSA と互換
- 最大運転圧力: 10.0 MPa (100 ハー)
- セル温度: 20~50° C、5° C刻み
- 温度安定性: < 0.001° C
- ヘースラインノイス: < 0.2 nS/cm、連続サフレッションの平均値
- キャヒラリー: ID 0.18 mm

MagIC Net 4.1以上に対応

889 IC Sample Center – cool

889 IC サンフルセンタ – cool は、使用てきるサンフルかこく少量てある場合の適切なオートメーションのソリューションてす。889 IC サンフルセンタに対して本製品は更に冷却機能を有しているのて、生化学的に重要な、または熱化学的に不安定なサンフルに最適なサンフルチェンシャーてす。