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 0.0250.25 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 15100 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	15100 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 0.140 µg/L with quadratic fits resulted in R^2 values in the range of 0.9960.999. 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%).

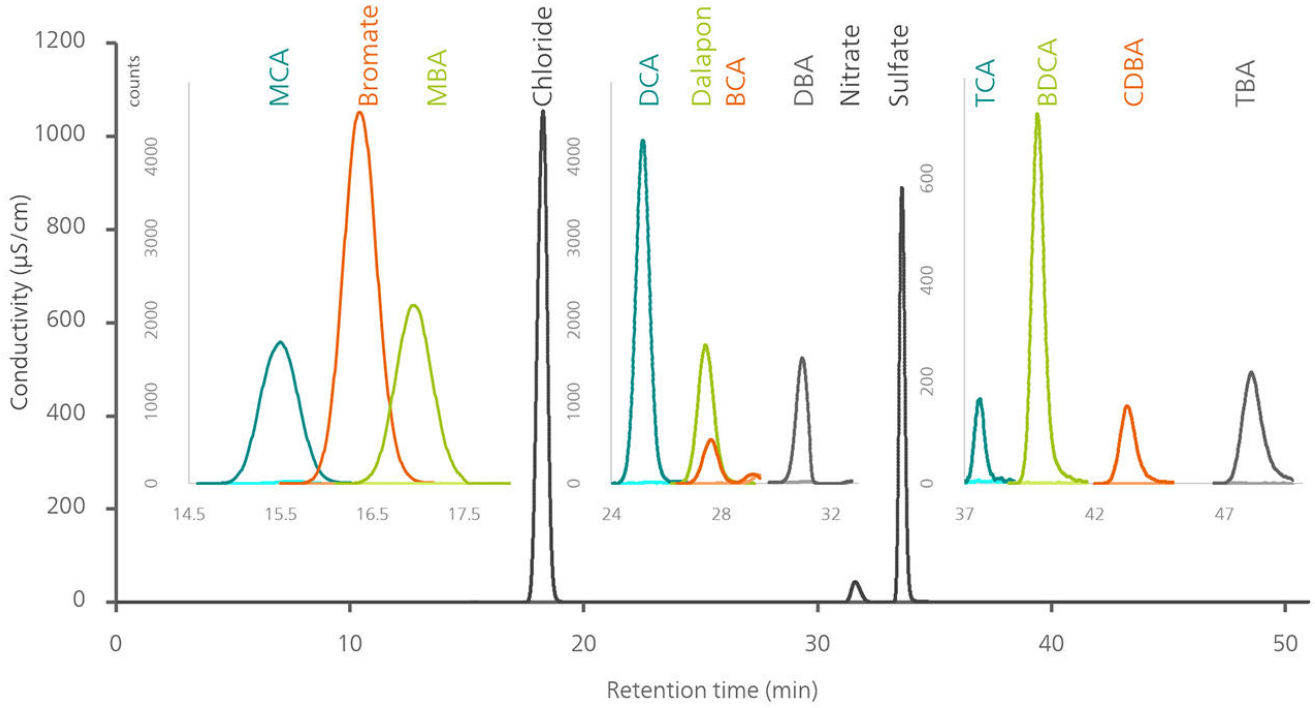

Figure 3. Overlay of a chromatogram of laboratory synthetic sample matrix (LSSM) according to EPA 557 with c(ammonium chloride) = 100 mg/L, c(nitrate) = 20 mg/L, c(hydrogen carbonate) = 150 mg/L, c(chloride) = 250 mg/L, and c(sulfate) = 250 mg/L (light colored lines), and of LSSM spiked with 1 µg/L of 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 65115% (for LSSM), 46112% (for tap water), and 87150% (for Evian water). Replicates for tap water (n = 7) were in the range of 0.76.8% RSD (relative standard deviation). For mineral water (Evian) (n = 6) and for LSSM (n = 7) RSD values were in the range of 1.66.3% and 1.036.5%, 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 50150%). *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*	91109
Monobromoacetic acid	MBAA	17.2	137	79	0.025*	88112
Bromate	BrO_3	16.7	127	111	0.025*	84116
Dichloroacetic acid	DCAA	25.6	127	83	0.025	84116
Dalapon	DAL	28.0	141	97	0.025	74126
Bromochloroacetic acid	BCAA	28.0	173	81	0.05	74126
Dibromoacetic acid	DBAA	31.4	217	173	0.025	75125
Trichloroacetic acid	TCAA	37.9	161	117	0.25	62131
Bromodichloroacetic acid	BDCAA	40.2	163	81	0.025	79121
Chlorodibromoacetic acid	CDBAA	43.5	207	79	0.025	52148
Tribromoacetic acid	TBAA	49.1	251	79	0.025	62138

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

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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).
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CONFIGURATION

940 Professional IC Vario TWO/SeS/PP/MB

940 Professional IC Vario TWO/SeS/PP 是智能型**双通道**离子色谱仪器,带有**序列抑制**(单通道)和一个用于抑制器再生的**蠕动泵**。该仪器可使用任意分离和检测方法。

典型的应用范围:

- 并行测定阴离子和阳离子的标准仪器
- 阴离子和阳离子的痕量分析
- 阴离子和阳离子的在线监控
- 针对微孔 (2mm) 应用经过优化,尤其适合耦合技术(IC-MS 或 IC-ICP/MS)

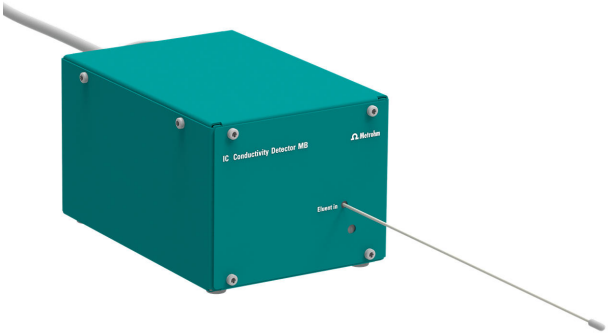
支持 MagIC Net 4.1 和以上版本

Metrosep A Supp 19 - 150/4.0

出色的分离性能和高容量 - Metrosep A Supp 19 产品系列因此在色谱柱产品品类中脱颖而出。其特点在于较好的峰对称性和选择性,以及较高的热、机械和化学稳定性,其因此在更高流速和压力下极其坚固和稳定。

150 mm 仪器型号被认为是阴离子色谱的标准色谱柱,因为其可靠解决了大多数应用,并且用途非常广泛。Metrosep A Supp 19 - 150/4.0 分离柱容量高,因此特别适用于具有要求严苛基质的复杂应用。Metrosep A Supp 19 - 150/4.0 具有出色的分离性能,因此应用领域非常广泛,例如包括以下应用:

- 测定各种水样中的标准阴离子(氟离子、氯离子、亚硝酸根、溴离子、硝酸根、磷酸根和硫酸根);
- 测定复杂样品基质中的标准阴离子和有机酸,例如:环境或食品样品;
- 测定锅炉给水中的标准阴离子和有机酸,保障电厂安全运行;
- 测定药物样品中的标准阴离子。



IC Conductivity Detector MB

用于智能型离子色谱仪的紧凑智能型高性能电导检测器。针对微孔柱经过优化。卓越的温度稳定性,在受保护的检测器端子板内完成整个信号处理过程以及最新一代的 DSP(数字式信号处理)均能确保测量的最高精确性。归功于动态工作范围,无需进行(也包括非自动)范围变更。

典型的应用范围:

- 阴离子或阳离子测定,化学抑制、序列抑制法或无抑制及电导检测
- 针对微孔 (2mm) 应用经过优化,尤其适合耦合技术(IC-MS 或 IC-ICP/MS)

规格说明书概览:

- 0 ... 15000 µS/cm 无区段切换
- 测量池容量:0.3 µL
- 由不锈钢 X2CrNiMo17-12-2 (316 L) 制成的环形电极,与 MSA 兼容
- 最大工作压力:10.0 MPa (100 bar)
- 池温:20 ... 50 ° C,步幅为 5 ° C
- 温度稳定性: 0.001 ° C
- 基线噪音:° 0.2° nS/cm,是使用序列抑制法的典型值
- 毛细管:ID 0.18 mm

支持 MagIC Net 4.1 和以上版本

889 IC Sample Center – cool

889 IC Sample Center – cool 这种自动化解决方案也适用于样品量极少的情况。与 889 IC Sample Center 相比,它还具有冷却功能,因此是用于生物化学相关领域或热稳定性差的样品的最佳自动进样器。