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)

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%).

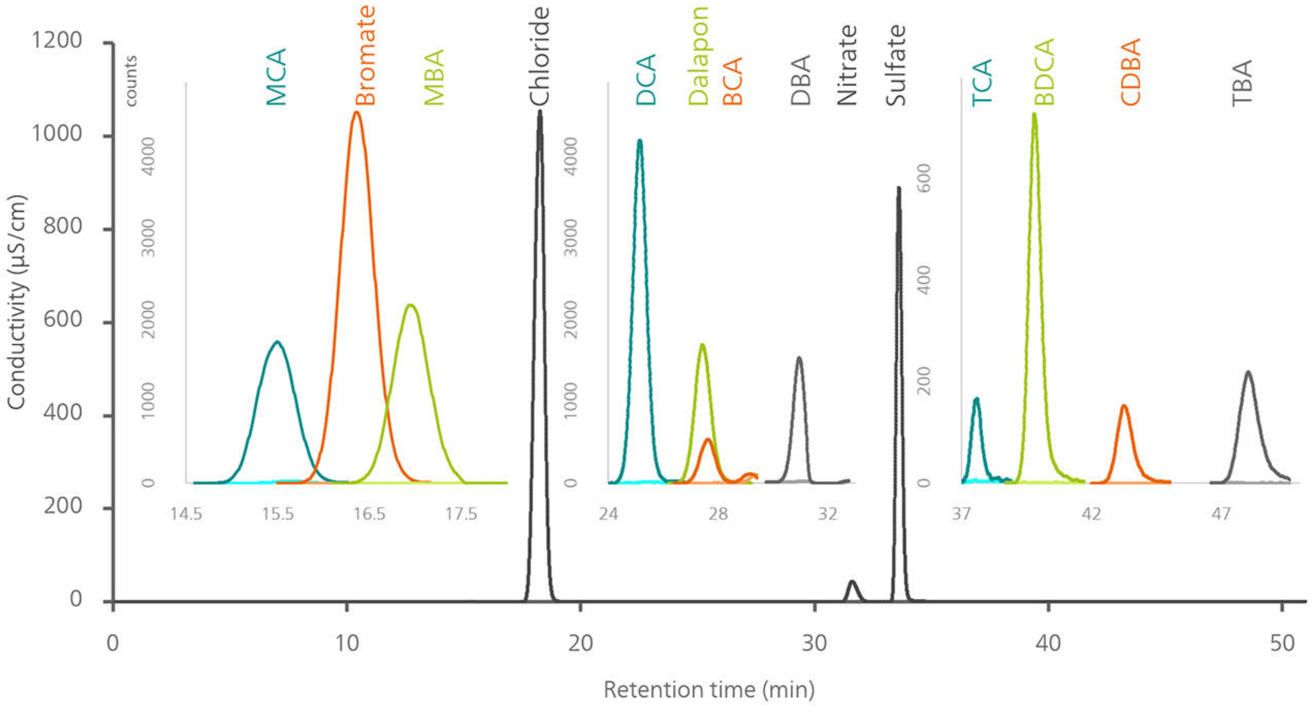

Figure 3. Overlay of a chromatogram of laboratory synthetic sample matrix (LSSM) according to EPA 557 with c(ammonium chloride) = 100 mg/L, c(nitrate) = 20 mg/L, c(hydrogen carbonate) = 150 mg/L, c(chloride) = 250 mg/L, and c(sulfate) = 250 mg/L (light colored lines), and of LSSM spiked with 1 µg/L of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

RESULTS

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

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CONFIGURATION

940 Professional IC Vario TWO/SeS/PP/MB

The 940 Professional IC Vario TWO/SeS/PP is the intelligent **two-channel** IC instrument with **sequential suppression** (one channel) and a **peristaltic pump** for suppressor regeneration. The instrument can be used with any separation and detection methods.

Typical areas of application:

- Standard instrument for parallel anion and cation determinations
- Trace analysis for anions and cations
- Online monitoring for anions and cations
- Optimized for microbore (2 mm) applications, ideally suitable for coupling techniques (IC-MS or IC-ICP/MS)

Supported with MagIC Net 4.1 and higher

Metrosep A Supp 19 - 150/4.0

Outstanding separation properties and high-capacity – these are the things which clearly distinguish the Metrosep A Supp 19 product family from the rest of the column portfolio. It features best peak symmetries and selectivities as well as high thermal, mechanical and chemical stability, which makes it extremely robust and stable in the presence of higher flow rates and pressures.

The 150 mm version is considered the standard column for anion chromatography, as it reliably solves the lion's share of applications and is very versatile in its use. Thanks to its high capacity, the Metrosep A Supp 19 - 150/4.0 separation column is particularly well suited even for complex applications with sophisticated matrices. The range of applications of the Metrosep A Supp 19 - 150/4.0 is very versatile, thanks to its outstanding separation properties and comprises the following applications, for example:

- Determination of standard anions (fluoride, chloride, nitrite, bromide, nitrate, phosphate and sulfate) in a wide variety of water samples;
- Determination of standard anions and organic acids in complex sample matrices, e.g. environmental or food samples;
- Determination of standard anions and organic acids in boiler feed water to ensure the safe operation of power plants;
- Determination of standard anions in pharmaceutical samples.

IC Conductivity Detector MB

Compact and intelligent high performance conductivity detector for intelligent IC instruments. Optimized for microbore columns. Outstanding temperature stability, the complete signal processing within the protected detector block and the latest generation of DSP – Digital Signal Processing – guarantee the highest precision of the measurement. No change of measuring ranges (not even automatic ones) is required, due to the dynamic working range.

Typical areas of application:

- Anion or cation determinations with chemical suppression, sequential suppression or without suppression and conductivity detection
- Optimized for microbore (2 mm) applications, ideally suitable for coupling techniques (IC-MS or IC-ICP/MS)

Specification at a glance:

- 0–15000 µS/cm without range switching
- Cell volume: 0.3 µL
- Ring-shaped electrodes made of stainless steel X2CrNiMo17-12-2 (316 L), compatible with MSA
- Maximum operating pressure: 10.0 MPa (100 bar)
- Cell temperature: 20–50 °C in increments of 5 °C
- Temperature stability: 0.001 °C
- Baseline noise: 0.2 nS/cm typical for sequential suppression
- Capillaries: ID 0.18 mm

Supported with MagIC Net 4.1 and higher

889 IC Sample Center – cool

The 889 IC Sample Center – cool is the appropriate automation solution when you have only a very small amount of sample. In comparison with the 889 IC Sample Center, it possesses in addition a cooling function and is thus the ideal sample changer for biochemically relevant or thermally unstable samples.