Application Note: 454

Analysis of Haloacetic Acids in Drinking Water by IC-MS/MS

Charles Yang[1] and Stacy Henday[2]
[1]Thermo Fisher Scientific, San Jose, CA; [2]Dionex Corporation, Sunnyvale, CA

Key Words

- TSQ Quantum Access
- EPA
- Ion chromatography
- Water analysis

Introduction

Haloacetic acids (HAAs) are formed as disinfection by-products when water is chlorinated to remove microbial content. The chlorine reacts with naturally occurring organic and inorganic matter in the water, such as decaying vegetation, to produce by-products that include HAAs. Of the nine species of HAAs, five are currently regulated by the EPA (HAA5): monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), and dibromoacetic acid (DBAA). The remaining four HAAs are unregulated: bromochloroacetic acid (BCAA), bromodichloroacetic acid (BDCAA), dibromochloroacetic acid (DBCAA), and tribromoacetic acid (TBAA).

According to the U.S. Environmental Protection Agency (EPA), there might be an increased risk of cancer associated with long-term consumption of water containing levels of HAAs that exceed 0.6 mg/L.[1] EPA Methods 552.1, 552.2, and 552.3, are used to determine the level of all nine HAAs in drinking water.[2,3,4] These methods require derivatization and multiple extraction steps followed by gas chromatography (GC) with electron capture detection (ECD).

In comparison to the conventional EPA methods using GC with ECD, the combination of ion chromatography and mass spectrometry (IC-MS and IC-MS/MS) offers sensitive and rapid detection without the need for sample pre-treatment. Ion chromatography is a form of liquid chromatography that uses ion-exchange resins to separate atomic and molecular ions. The retention time in the column is predominantly controlled by the interactions of the ions of the solute with the resin. Coupling IC with the highly selective detection of a triple quadrupole mass spectrometer allows unambiguous identification of substance peaks. Matrix interference effects are greatly reduced, which improves the sensitivity and lowers the detection limits.

In the method described here, water samples can be injected directly into an ion chromatography system that is coupled to a Thermo Scientific TSQ Quantum Access triple stage quadrupole mass spectrometer. The separation of all nine HAAs addressed in the EPA methods is achieved with an anion-exchange column using an electrolytically formed hydroxide gradient.

Goal

To develop a simple, rapid, and sensitive IC-MS/MS method for analyzing haloacetic acids in water.

Experimental Conditions

Ion Chromatography

IC analysis was performed on a Dionex ICS 3000 system (Dionex Corporation, Sunnyvale, CA). Samples were directly injected and no sample pre-treatment was required. The IC conditions used are shown in Table 1.

Column Set:	Dionex IonPac® AG24 (2 × 50 mm), IonPac AS24 (2 × 250 mm)
Suppressor:	ASRS® 300, 2 mm
Column Temperature:	15 °C
Injection Volume:	100 µL
Flow Rate:	0.3 mL/min KOH gradient, electrolytically generated (Table 2)

Table 1. Ion chromatography system conditions

Retention Time (min)	[KOH] mM
0.00	7.0
15.1	7.0
30.8	18.0
31.0	60.0
46.8	60.0
47.0	7.0

Table 2. Electrolytically formed hydroxide gradient details

The separation performed on the IonPac AS24 column used a hydroxide gradient. It is known that hydroxide is not a recommended eluent for mass spectrometers. The addition of an ASRS 300 anion self-regenerating suppressor is critical. This suppressor is placed in line after the column and electrolytically converts the hydroxide into water, making the separation compatible with mass spectrometric detection. See Figure 1.

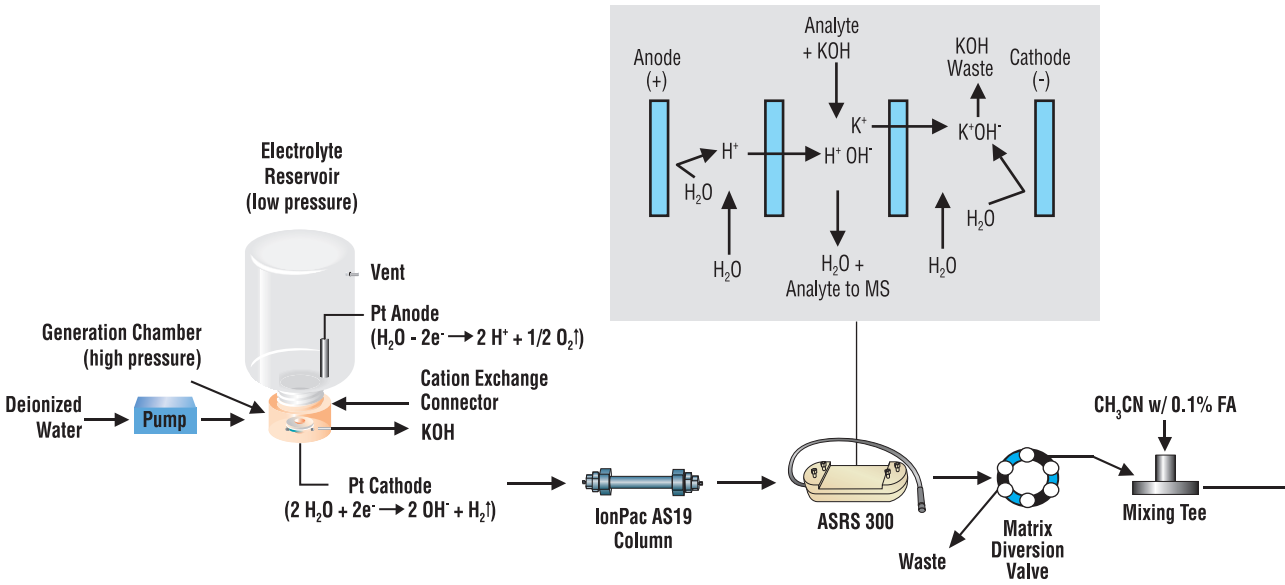


Figure 1: Flow schematic of the IC-MS/MS system

In addition, a matrix diversion valve was placed in line prior to the mass spectrometer. This valve functions to divert the high sample matrix waste from the MS source, prolonging the time in between cleanings. Acetonitrile was teed into the eluent stream after the matrix diversion valve. The acetonitrile had two main purposes: to assist in the desolvation of the mobile phase and to act as a make-up flow when the IC eluent was diverted to waste.

Mass Spectrometry

MS analysis was carried out on a TSQ Quantum Access™ triple stage quadrupole mass spectrometer with a heated electrospray ionization (H-ESI) probe. The MS conditions used are shown in Table 3.

Ion source polarity:	Positive ion mode
Spray voltage:	4000 V
Sheath gas pressure:	40 units
Auxiliary gas pressure:	15 units
Capillary temperature:	270 °C

Table 3. Mass spectrometer conditions

Individual standards were infused into the mass spectrometer to determine optimum tube lens settings and collision energies for the product ions. Table 4 describes the MS conditions for specific HAAs and internal standards.

Analyte	Q1 (m/z)	Q3 (m/z)	CE (V)	Tube Lens (V)	Skimmer Offset (V)	Scan Time (s)
MCAA	93.01	35.60	10	26	0	1.25
MBAA	136.99	79.09	12	33	0	1.25
DCAA	127.02	83.20	11	26	0	1.25
DBAA	214.80	79.20	24	33	0	1.25
BCAA	171.00	79.20	35	44	0	1.25
TCAA	161.06	117.10	10	69	0	1.60
BDCAA	79.00	79.00	15	30	0	1.60
DBCAA	206.74	79.13	15	30	0	2.50
TBAA	250.70	79.10	25	26	0	2.50
MCAA-ISTD	94.01	35.60	10	26	0	1.25
MBAA-ISTD	138.00	79.09	12	33	0	1.25
DCAA-ISTD	128.01	84.20	11	26	0	1.25
TCAA-ISTD	162.06	118.10	10	69	0	1.60

Table 4. MS conditions for the various HAAs and internal standards

TSQ Quantum Access™

The status of the ion chromatography system was monitored at the same time as the MS data acquisition, as shown in Figure 2.

Results and Discussion

The separation of the nine HAAs is shown in Figure 3. The selectivity of the IC-MS/MS system allows separation of the HAAs from common inorganic matrix ions. This allows matrix peaks of chloride, sulfate, nitrate, and bicarbonate to be diverted to waste during the analytical run and avoids premature fouling of the ESI-MS/MS instrument source.

An internal standard mixture of ^{13}C labeled MCAA, MBAA, DCAA, and TCAA was spiked into each sample at 3 ppb. The calibration curves were generated using internal standard calibrations for all of the HAA compounds in water. Excellent linearity results were observed for all compounds as shown in Figures 4, 5, and 6. Analytes were run at levels of 250 ppt to 20 ppb. It must be noted that the TCAA analyte could not be

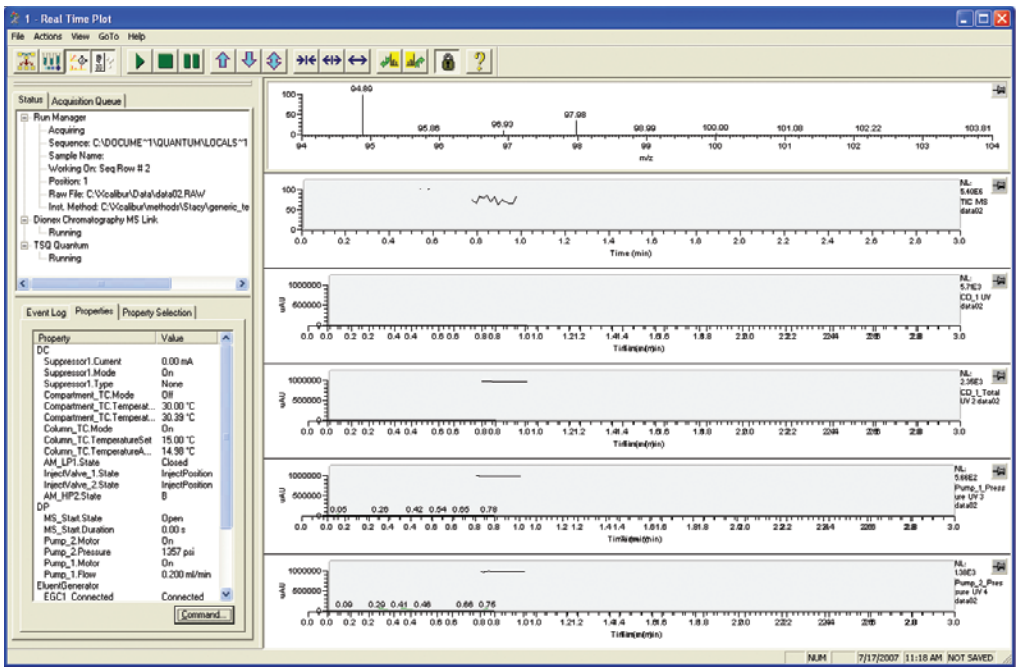
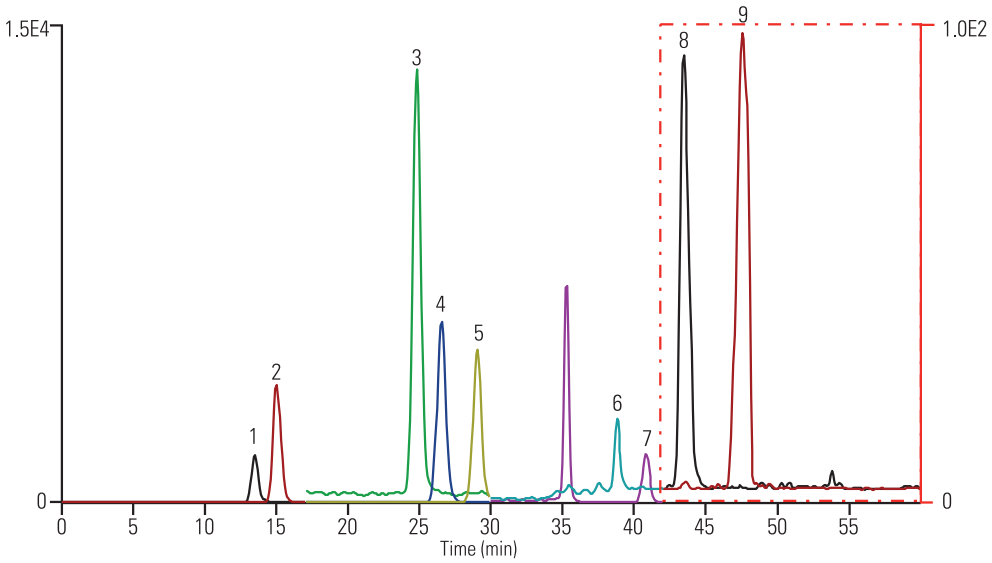


Figure 2: These chromatograms show the progress of the pump pressure and front end detector data along with the TSQ Quantum Access MS data. The left side of the screen shows the status of the ion chromatography system and the status of the TSQ Quantum Access.

detected at levels below 2.5 ppb. TCAA sensitivity is very strongly correlated with the source temperature of the mass spectrometer. To improve the TCAA detection, the temperature was lowered. However, lowering the temperature impacted the detection of the other eight analytes. This phenomenon of TCAA temperature sensitivity has been reported in studies with other MS instrumentation configurations.[5]

To test the recoveries of all nine HAAs, spiked matrix samples were run in a matrix of 250 mg/L of each of chloride and sulfate, 150 mg/L of bicarbonate, 30 mg/L of



1. Monochloroacetic acid (MCAA)
2. Monobromoacetic acid (MBAA)
3. Dichloroacetic acid (DCAA)
4. Bromochloroacetic acid (BCAA)
5. Dibromoacetic acid (DBAA)
6. Trichloroacetic acid (TCAA)
7. Bromodichloroacetic acid (BDCAA)
8. Dibromochloroacetic acid (DBCAA)
9. Tribromoacetic acid (TBAA)

Figure 3: Separation and detection of the nine haloacetic acids using an ISC-3000 system with an IonPac AS24 column, coupled to a TSQ Quantum Access MS/MS system. Analyte levels were 2.5 ppb each in deionized water with an injection volume of 100 µL.

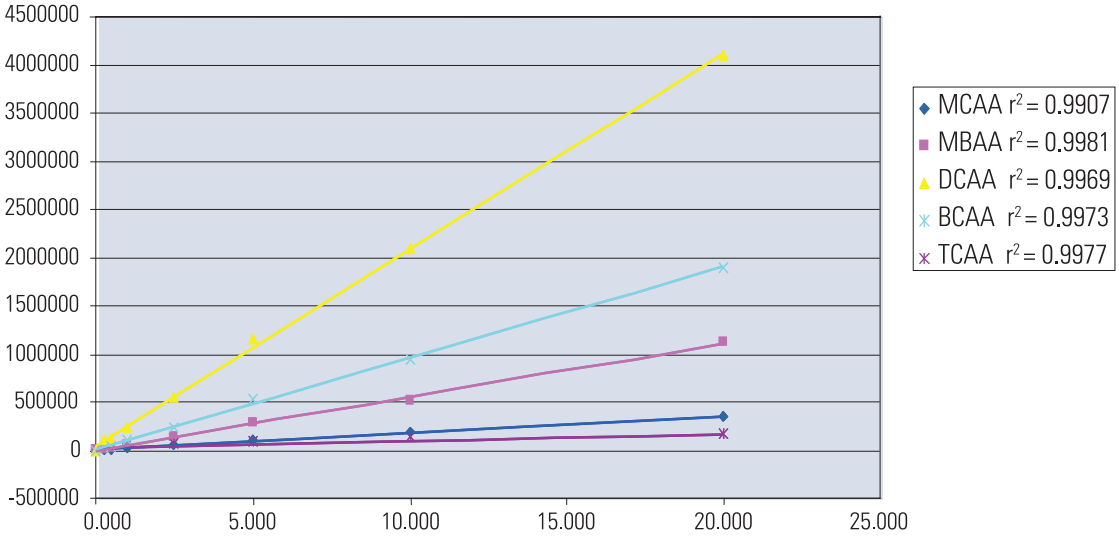


Figure 4: Calibration curve overlay of the HAA compounds in water by IC-MS/MS

nitrate, and 100 mg/L ammonium chloride preservative, for a total chloride concentration of 316 mg/L. The results are shown in Table 5. Excellent recoveries and reproducibility were achieved for most of the samples. However, difficulty was observed when quantitating low levels of DBCAA in matrix. DBCAA does not ionize as strongly as the other analytes in the method and is very susceptible to temperature changes in the column.

Method detection limits (Table 6) were calculated by seven replicate injections of 1.0 ppb of each analyte and the equation $MDL=t_{99\%}xS_{(n-7)}$, where: t is Student's t at 99% confidence intervals ($t_{99\%,\ n=7}$ = 3.143) and S is the standard deviation. Table 6 compares these results to the calculated MDL values of EPA Method 552.2, which uses liquid-liquid extraction and methylation of the carboxylic acids before determination by GC-ECD. The results obtained by the IC-MS/MS method were comparable to those achieved in EPA Method 552.2.

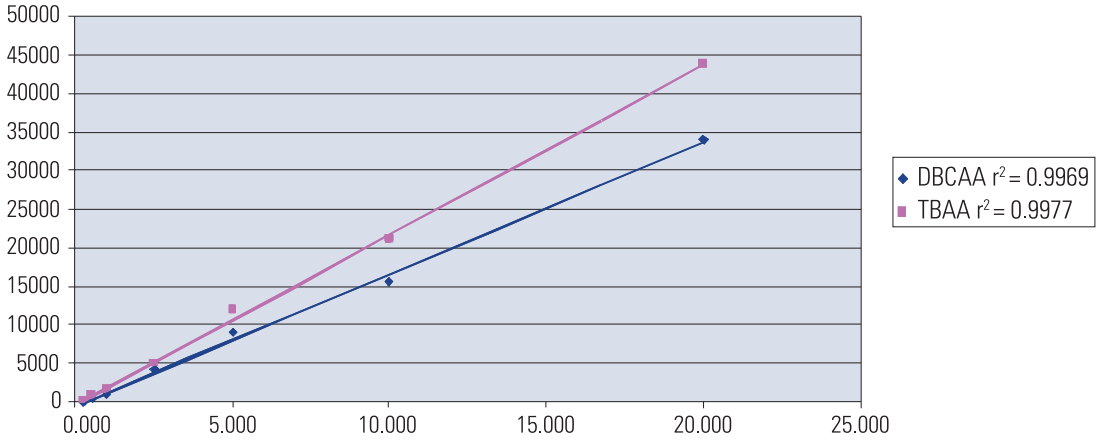


Figure 5: Overlay of calibration curves of dibromochloroacetic acid and tribromoacetic acid in water by IC-MS/MS

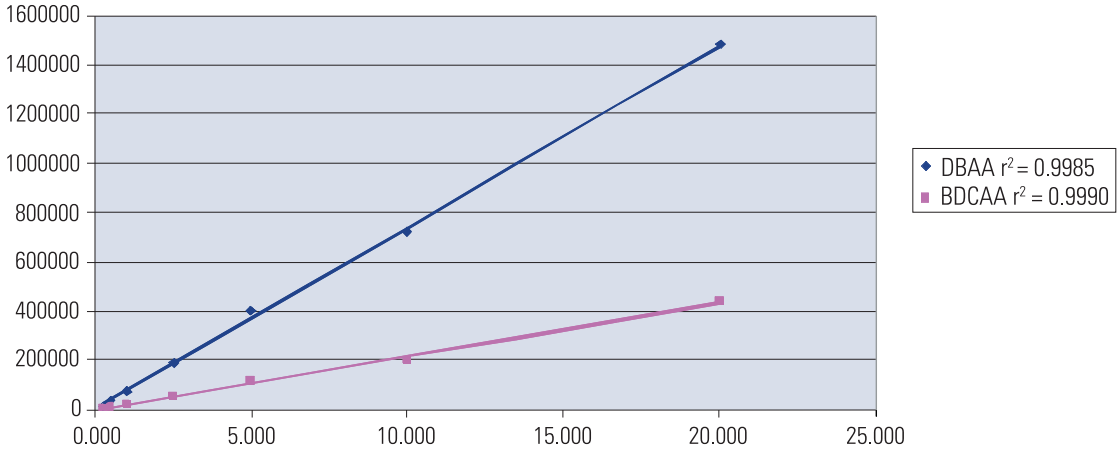


Figure 6: Overlay of calibration curves of dibromoacetic acid and bromodichloroacetic acid in water by IC-MS/MS

Analyte	Average RT	%RSD RT	Average Area	%RSD Area
MCAA	12.59	0.00	764439	2.34
MBAA	14.06	0.27	1627886	2.91
DCAA	24.44	0.02	11236488	3.98
BCAA	26.88	0.18	2468467	4.85
DBAA	30.09	0.16	731710	3.26
TCAA	39.05	0.24	4855405	10.98
BDCAA	45.13	0.04	1212887	4.78
DBCAA	43.55	0.07	1064	22.20
TBAA	47.44	0.25	1333	17.60

Table 5. Reproducibility of area and retention time in the TSQ Quantum Access for seven injections of 2 ppb concentration in simulated matrix

Analyte	Calculated MDL (µL/L)	EPA Method 552.2 MDL (µL/L)
MCAA	0.203	0.273
MBAA	0.392	0.204
DCAA	0.097	0.242
BCAA	0.136	0.251
DBAA	0.100	0.066
TCAA	0.403	0.079
BDCAA	0.159	0.091
DBCAA	0.459	0.468
TBAA	0.407	0.820

Table 6. Calculated MDL response of HAA9 on the TSQ Quantum Access

Conclusion

IC-MS/MS is a powerful tool used in the quantitation of haloacetic acid samples. When compared to the conventional EPA methods using GC with electron capture, using IC-MS/MS to analyze for haloacetic acids saves analysts several hours of sample preparation because there is no requirement for sample pre-treatment. The resolution between the matrix peaks and haloacetic acids is excellent, which allows for minimum interference in detection.

Excellent recoveries and reproducibility were achieved when samples were spiked into a simulated matrix containing 250 mg/L of each of chloride and sulfate, 150 mg/L bicarbonate, 30 mg/L of nitrate and 100 mg/L ammonium chloride preservative for a total chloride concentration of 316 mg/L. Results are comparable to those achieved in EPA Method 552.2.

References

1. U.S. Environmental Protection Agency, *Microbial Health Effects Tables: Potential Adverse Health Effects from High/Long-term Exposure to Hazardous Chemicals in Drinking Water,* **2002**.
2. U.S. Environmental Protection Agency, Method 552.1, *Determination of Haloacetic Acids and Dalapon in Drinking Water by Ion Exchange Liquid-Solid Extraction and Gas Chromatography with Electron Capture Detection,* Rev. 1.0, **1992**.
3. U.S. Environmental Protection Agency, Method 552.2, *Determination of Haloacetic Acids and Dalapon in Drinking Water by Liquid-Liquid Extraction, Derivatization, and Gas Chromatography with Electron Capture Detection,* Rev 1.0, **1995**.
4. U.S. Environmental Protection Agency, Method 552.3, *Determination of Haloacetic Acids and Dalapon in Drinking Water Liquid-Liquid Microextraction, Derivatization, and Gas Chromatography with Electron Capture Detection,* Rev 1.0, **2003**.
5. Slignsby, R.; Saini, C.; Pohl, C.; Jack, R. *The Measurement of Haloacetic Acids in Drinking Water Using IC-MS/MS–Method Performance,* Presented at the Pittsburgh Conference, New Orleans, LA, March **2008**.

***View additional Thermo Scientific LC/MS application notes at:* www.thermo.com/appnotes**

In addition to these offices, Thermo Fisher Scientific maintains a network of representative organizations throughout the world.

Africa-Other
+27 11 570 1840
Australia
+61 2 8844 9500
Austria
+43 1 333 50 34 0
Belgium
+32 2 482 30 30
Canada
+1 800 530 8447
China
+86 10 8419 3588
Denmark
+45 70 23 62 60
Europe-Other
+43 1 333 50 34 0
Finland/Norway/Sweden
+46 8 556 468 00
France
+33 1 60 92 48 00
Germany
+49 6103 408 1014
India
+91 22 6742 9434
Italy
+39 02 950 591
Japan
+81 45 453 9100
Latin America
+1 608 276 5659
Middle East
+43 1 333 50 34 0
Netherlands
+31 76 579 55 55
South Africa
+27 11 570 1840
Spain
+34 914 845 965
Switzerland
+41 61 716 77 00
UK
+44 1442 233555
USA
+1 800 532 4752

www.thermo.com

Thermo Fisher Scientific, San Jose, CA USA is ISO Certified.

AN62963_E 01/09S