Introduction

Ion chromatography (IC) and capillary zone electrophoresis (CE) have been examined for the simultaneous determinations of anions in seawater samples. In these measurements, it is important to remove any interferences due to large amounts of matrix ions. In IC employing polymer-based anion exchange columns, high concentrations of inorganic solutions, sodium chloride and lithium chloride as eluents, and a UV detector, nitrite (NO$_2^-$), bromide (Br$^-$), and nitrate (NO$_3^-$) in seawater were directly detected without interferences by matrix anions, such as chloride (Cl$^-$) and sulfate (SO$_4^{2-}$).$^{1,2}$ A similar method is possible using quaternary ammonium (cetyltrimethylammonium (CTA$^+$) or dilauryldimethylammonium (DDA$^+$))-coated octadecylsilyl (ODS) columns or silica columns with high anion-exchange capacities as separation columns.$^{3-7}$ The use of an ODS column—dilute octylammonium phosphate eluent for Br$^-$, NO$_2^-$, NO$_3^-$, and I$^-$|$^{8,9}$ and a Zwittergent$^\text{®}$ 3 - 14 coated ODS column—dilute sodium perchlorate eluent for Br$_5$, NO$_2^-$, and I$^-$$^{10}$ are other approaches for anion determination in seawater. A column-switching IC is a useful technique to remove any interferences by matrix ions, and was applied to the determination of some anions (NO$_2^-$, NO$_3^-$, and Br$^-$ etc., samples were 5 times diluted for determination) or BrO$_3^-$ by conductivity (CD) detection, and also IO$_3^-$ by UV detection.$^{11}$ IC with ICP-MS was applied to the determination of BrO$_3^-$ and Br$^-$ or IO$_3^-$ and I$^-$ in seawater. By using CE with UV, NO$_2^-$ and NO$_3^-$|$^{12}$ and I$^-$|$^{13,14}$ and BrO$_3^-$|$^{15}$ were determined with different CE conditions coupled with transient isotachophoresis (t-ITP) for the on-line preconcentration of analyte anions.

The determination of those anions in seawater is of importance to understand environmental conditions and for coastal/marine research.$^{12,15-21}$ For determination, it is desirable to be able to measure many anions with high sensitivity within a short time for one sample. Recently, we have examined the separation and detection of six anions using conventional silica-based and polymer-based particulate ODS columns coated with DA$^+$$^{22}$ for the first time the determinations of six anions in seawater in a single run. However, it took a long time for each determination.
(25 min per one sample).

The aim of this study is to develop a fast and sensitive IC method for the simultaneous determinations of six anions (IO$_3^-$, BrO$_3^-$, Br$^-$, NO$_2^-$, NO$_3^-$, and I$^-$) in seawater samples. Since monolithic ODS columns have high permeability, owing to the high porosity, high flow rates of the eluent were possible. Hydrophilic inorganic anions (NO$_2^-$, Br$^-$, and NO$_3^-$) were separated within 3 min at a flow rate of 3 ml/min using DDA$^+\text{-coated monolithic ODS columns.}$ However, IO$_3^-$ with hydrophilicity was almost eluted at the position of the injection peak, and I$^-$ with hydrophobicity was largely delayed (retention time, ca. 16 min). In this study, an IC system with fast separation and high sensitivity was examined by using DA$^+\text{-coated monolithic ODS columns; the results were compared with the results by DDA$^+$-coated monolithic ODS columns.}$ The optimized IC system was applied to fast and sensitive determinations of low levels of anions in real seawater samples without sample dilution.

**Experimental**

**Apparatus**

The IC system used in this study consisted of a mobile-phase delivery pump (PU-2085 plus, Jasco, Tokyo, Japan, or DP-8020, Tosoh, Tokyo, Japan), an auto-sampler with 500-μL sample loop (AS 8020, Tosoh) or a Rheodyne 7125 injector with 100-μL sample loop (Cotati, USA), a UV-VIS detector (UV 2070 plus, Jasco), and a data processor (C-R8A, Shimadzu, Kyoto, Japan). Separation was achieved on the following silica-based monolithic octadecysilyl (ODS) columns connected in series: Chromolith Speed ROD RP-18e (50 × 4.6 mm i.d.) and Chromolith RP-18e (100 × 4.6 mm i.d.) (Merck KGaA, Darmstadt, Germany). The ODS columns have end-capped silica surfaces, but are only different in the column length. The columns of three different lengths were tested: 150 mm (50 + 100 mm columns), 300 mm (2 sets of (50 + 100 mm columns)), and 450 mm (3 sets of (50 + 100 mm columns)). The column temperature was controlled at 25°C.

**Reagents, mobile phases, and seawater samples**

The column temperature was controlled at 25°C. Solutions were prepared by mixing and diluting stock solutions of each anion (10 g L$^{-1}$). For DA$^+\text{-coated monolithic ODS columns (Chromolith Speed ROD RP-18e (50 × 4.6 mm i.d.) + Chromolith Performance RP-18e (100 × 4.6 mm i.d.))}; sample, IO$_3^-$ (5 mg L$^{-1}$), BrO$_3^-$ (5 mg L$^{-1}$), Br$^-$ (20 mg L$^{-1}$), NO$_2^-$ (1 mg L$^{-1}$), NO$_3^-$ (1 mg L$^{-1}$), and I$^-$ (1 mg L$^{-1}$) in pure water; sample volume, 200 μL; flow rate, 1 mL min$^{-1}$; UV detection wavelength, 225 nm.

![Fig. 1 Logarithm of the retention factor (log k) for each anion as a function of the eluent pH. Eluent, 0.1 M NaCl + 0.5 mM DAC + 5 mM phosphate buffer; separation column, DA$^+$-coated monolithic ODS columns (Chromolith Speed ROD RP-18e (50 × 4.6 mm i.d.) + Chromolith Performance RP-18e (100 × 4.6 mm i.d.)); sample, IO$_3^-$ (5 mg L$^{-1}$), BrO$_3^-$ (5 mg L$^{-1}$), Br$^-$ (20 mg L$^{-1}$), NO$_2^-$ (1 mg L$^{-1}$), NO$_3^-$ (1 mg L$^{-1}$), and I$^-$ (1 mg L$^{-1}$) in pure water; sample volume, 200 μL; flow rate, 1 mL min$^{-1}$; UV detection wavelength, 225 nm.](image)

Preparation of separation columns

Monolithic ODS columns were coated with an aqueous 2 mM DAC solution of NaCl-free to detect an end-point of adsorption by conductivity detection. The DAC solution was passed through the columns at a flow rate of 0.4 mL min$^{-1}$ at 25°C. Completion of column coating was confirmed by a rapid increase in the conductivity of the eluent. The amount adsorbed was approximately 0.28 mmol per 30 cm column in length. After coating, the eluent was changed to a NaCl solution containing 0.5 mM DAC and 5 mM phosphate buffer (pH 4.5), and was fed for ca. 20 h at a flow rate of 1.0 mL min$^{-1}$. The addition of NaCl in the DAC solution increased the anion retention because NaCl in the eluent promoted hydrophobic adsorption of dodecyl groups of DAC with octadecyl groups on the columns, and consequently constant anion retention times were obtained. Since the pK$_a$ of n-dodecyl amine is 10.63$^{26}$ and the pH of the eluent was 4.5, it was present as the dodecylammonium cation in this study. The stability and reproducibility of the coated columns were always checked by the retention times of the analyte anions and the base-line stability. For a determination, since the prepared columns were equilibrated continuously with the eluent, e.g. 0.3 M NaCl containing 0.5 mM DAC and 5 mM phosphate buffer (pH 4.5), the retention times of the analytes were constant during this study.

Replacement and recoating of the column were unnecessary in this study.

A preparation method of DDA$^+$-coated monolithic ODS columns (150 × 4.6 mm i.d.) is described elsewhere.$^7$ The amounts adsorbed were approximately 0.19 mmol per the columns used in this study. After preparation, the eluent was changed to NaCl solutions containing 5 mM phosphate buffer (pH 5.0). It was not necessary to add dilauryldimethylammonium bromide (DDAB) in the NaCl eluent, because the DDA$^+$-coated
on the monolithic ODS columns did not dissolve owing to its high hydrophobicity.

Results and Discussion

Anion separation

The dependence of the separation of six anions on the pH of the eluent is shown in Fig. 1. At pH 4.0 – 5.5, the retention times of the anions increased in the following order: IO₃⁻ < BrO₃⁻ < Br⁻ < NO₂⁻ < NO₃⁻ < I⁻. On the other hand, below pH 4.0, the retention time of NO₂⁻ decreased when the eluent pH values decreased. Most of the NO₃⁻ (pKₐ = 3.4) is converted to neutral HNO₂ at pH 2.5, leading to weak retention. Thus, since good anion separation was obtained with eluent pH values greater than 4.5, an eluent of pH 4.5 was selected for subsequent experiments. The addition (0.5 mM) of DAC in the eluent was necessary to maintain constant anion retention by preliminary experiments, because the retention times of the anions decreased gradually with the eluent without addition of DAC.

The separation of the anions in (a) pure water and (b) 35% artificial seawater was examined with the different lengths of the monolithic ODS columns (150, 300, and 450 mm) (Fig. 2).

Fig. 2  Ion chromatograms of anions in (a) pure water and (b) 35% artificial seawater. Column length, (A) 150, (B) 300, (C) 450 mm; eluent, (A) 0.1 M NaCl, (B) 0.2 M NaCl, (C) 0.3 M NaCl, each eluent contains 0.5 mM DAC + 5 mM phosphate buffer (pH 4.5); sample, 1) IO₃⁻ (0.5 mg L⁻¹), 2) BrO₃⁻ (1 mg L⁻¹), 3) Br⁻ (50 mg L⁻¹), 4) NO₂⁻ (0.1 mg L⁻¹), 5) NO₃⁻ (0.1 mg L⁻¹), and 6) I⁻ (0.1 mg L⁻¹); sample volume, 100 μL; flow rate, 1 mL min⁻¹; UV detection wavelength, 225 nm.

Fig. 3  Logarithm of the retention factor (log k) for anion as a function of the logarithm of the eluent concentration. (A) Eluent, 0.1 – 0.3 M NaCl + 0.5 mM DAC + 5 mM phosphate buffer (pH 4.5). Flow rate, 1 mL min⁻¹. Sample, anions in 35% artificial seawater. Other IC conditions are the same as for Fig. 2(B). (B) Eluent, 0.1 – 0.6 M NaCl + 5 mM phosphate buffer (pH 5); column, DDA⁺-coated monolithic ODS column (150 × 4.6 mm i.d.); sample, anions in 35% artificial seawater except for IO₃⁻ in pure water; sample volume, 200 μL; flow rate, 3 mL min⁻¹.
respectively. The differences between the retention times of artificial seawater with column pressures of 5.0 and 7.6 MPa, phosphate buffer (pH 4.5); flow rate, 2 mL min\(^{-1}\); sample, 1) IO\(_3^-\) with Fig. 3B (a 150-mm long DDA+-coated monolithic ODS (300 \(\times\) 4.6 mm i.d.); eluent, 0.3 M NaCl + 0.5 mM DAC + 5 mM phosphate buffer (pH 4.5); flow rate, 2 mL min\(^{-1}\); sample, 1) IO\(_3^-\) (0.5 mg L\(^{-1}\)), 2) BrO\(_3^-\) (1 mg L\(^{-1}\)), 3) Br\(^-\) (50 mg L\(^{-1}\)), 4) NO\(_2^-\) (0.1 mg L\(^{-1}\)), and 6) I\(^-\) (0.1 mg L\(^{-1}\)); sample volume, 100 \(\mu\)L; UV detection wavelength, 225 nm. (b) Column, DDA+-coated monolithic ODS columns (150 \(\times\) 4.6 mm i.d.; eluent, 0.5 M NaCl + 5 mM phosphate buffer (pH 5.0); flow rate, 3 mL min\(^{-1}\). Other IC conditions are the same as for Fig. 4(a) except for 1) IO\(_3^-\) (0.5 mg L\(^{-1}\)) + system peak and 2) BrO\(_3^-\) (0.5 mg L\(^{-1}\)).

0.5 mM DAC and 5 mM phosphate buffer (pH 4.5), respectively) were selected in order to obtain similar retention times for different lengths of the columns. The concentration of Br\(^-\) was set at a higher concentration than the other anions because it is typically present at higher concentrations in seawater. The separations of anions in pure water and artificial seawater were small in an average (\(n = 3\)) for example, 0.20 and 0.13 min for hydrophilic iodate for column length of 300 and 450 mm, respectively, and 0.15 and 0.21 min for iodide of hydrophobicity. The peak widths in artificial seawater were similar with 300 and 450 mm-columns: 0.78 \(\pm\) 0.02 and 0.74 \(\pm\) 0.02 min for iodate and 1.05 \(\pm\) 0.02 and 1.12 \(\pm\) 0.02 min for iodide, respectively. Thus, the 300 mm-column was selected for subsequent experiments because of fast separation and low analytical cost.

**Characteristics of DA\(^+\)-coated monolithic ODS columns**

The dependency of the retention of the anions in 35% artificial seawater samples. (a) Column, DA\(^+\)-coated monolithic ODS columns (300 \(\times\) 4.6 mm i.d.); eluent, 0.3 M NaCl + 0.5 mM DAC + 5 mM phosphate buffer (pH 4.5); flow rate, 2 mL min\(^{-1}\); sample, 1) IO\(_3^-\) (0.5 mg L\(^{-1}\)), 2) BrO\(_3^-\) (1 mg L\(^{-1}\)), 3) Br\(^-\) (50 mg L\(^{-1}\)), 4) NO\(_2^-\) (0.1 mg L\(^{-1}\)), and 6) I\(^-\) (0.1 mg L\(^{-1}\)). (b) Column, DDA+-coated monolithic ODS columns (150 \(\times\) 4.6 mm i.d.; eluent, 0.5 M NaCl + 5 mM phosphate buffer (pH 5.0); flow rate, 3 mL min\(^{-1}\). Other IC conditions are the same as for Fig. 4(a) except for 1) IO\(_3^-\) (0.5 mg L\(^{-1}\)) + system peak and 2) BrO\(_3^-\) (0.5 mg L\(^{-1}\)).

| Anion     | Retention time | Peak area | Peak height |
|-----------|----------------|-----------|-------------|
| IO\(_3^-\) | 0.02           | 0.19      | 0.13        |
| BrO\(_3^-\)| 0.02           | 0.75      | 0.73        |
| Br\(^-\)  | 0.01           | 0.17      | 0.11        |
| NO\(_2^-\)| 0.02           | 0.68      | 0.23        |
| NO\(_3^-\)| 0.02           | 0.41      | 1.1         |
| I\(^-\)   | 0.02           | 0.29      | 0.26        |

Sample, IO\(_3^-\) (0.5 mg L\(^{-1}\)), BrO\(_3^-\) (1 mg L\(^{-1}\)), Br\(^-\) (50 mg L\(^{-1}\)), NO\(_2^-\), NO\(_3^-\), I\(^-\) (0.1 mg L\(^{-1}\)) in 35% artificial seawater, sample injection volume, 100 \(\mu\)L.

Table 1: Repeatability of retention time, peak area, and peak height

The separation of anions in artificial seawater for both columns is shown in Fig. 4. For DA\(^+\)-coated monolithic ODS columns, the peaks from iodate to iodide are more equally spaced in the chromatogram, compared to the DDA+-coated monolithic ODS column. Fast separation at a flow rate of the eluent, 2 mL min\(^{-1}\) was obtained with column pressures of 9.5 MPa for DA\(^+\)-coated columns. For the silica-based particulate ODS column coated with DA\(^+\), it took a long time for determination (25 min per one sample). Since the column had high column pressures (13 - 14 MPa for new column and 16 - 17 MPa after one month use at the flow rate, 1 ml/min of eluent), it was difficult to further increase the flow rate. Increases in the eluent concentration have led to decreased retention and less than baseline resolution. Thus, it is difficult to achieve faster separation.

**Stabilities of DA\(^+\)-coated columns and validity**

The repeatability for the retention time and the peak signal for each anion in 35% artificial seawater is given in Table 1 for the IC system of DA\(^+\)-coated monolithic ODS columns (300 \(\times\) 4.6 mm i.d.) and the mobile phase of 0.3 M NaCl + 0.5 mM DAC + 5 mM phosphate buffer (pH 4.5) at a flow rate of 2 ml min\(^{-1}\). The relative standard deviations (RSDs) for five successive measurements were less than 1.2% for the retention time, peak height, and peak area. The RSDs of the retention times (average 0.02%) were lower compared to those (average 0.62%) obtained for the 0.2 M NaCl eluent. These results show that the present IC system (column, eluent, and UV detector) was more stable for DA\(^+\)-coated columns.
has good stability. Also, the stabilities of the DA+-coated monolithic ODS column (column length of 300 mm) were evaluated by measuring the retention times of anions in artificial seawater by delivering the mobile phase. For example, the retention times of iodide with stronger retention were 10.04 ± 0.02 min (n = 10), 10.02 ± 0.03 min (n = 10), 10.02 ± 0.10 min (n = 48) for 7.4, 7.6, and 24 h, respectively. This is due to that a high concentration of NaCl in the eluent might stabilize the hydrophobic interaction between the dodecyl groups and the octadecyl groups, leading to stable column performance without any deterioration and a stable baseline for the use in this study.

Calibration data for each ion and the detection limits (DLs, signal to noise = 3 was used for calculation) are given in Table 2. Good calibration data were obtained for all of the anions. The DLs obtained for IO₃⁻, BrO₃⁻, Br⁻, NO₂⁻, NO₃⁻, and I⁻ with 100-μL injection were similar to those obtained by the DA+-coated particulate silica-based ODS column² and also for NO₂⁻, Br⁻, NO₃⁻, and I⁻ by DDA+-coated monolithic ODS column.³ With 200-μL injection, the DLs for IO₃⁻ and BrO₃⁻ were decreased to 4.8 and 12 μg L⁻¹, respectively, and better

Table 2 Calibration data (calibration curves and detection limits)

| Anion   | Linear range/ mg L⁻¹ | Calibration curve (Area (R²)) | Detection limit (S/N = 3 μg L⁻¹) |
|---------|----------------------|-------------------------------|----------------------------------|
| IO₃⁻    | 0 – 1                | y = 1.960 × 10x – 0.010 × 10⁴ | 7.7 (4.8)                        |
|         | (R² = 0.999)         |                               |                                  |
| BrO₃⁻   | 0 – 2                | y = 7.584 × 10x – 0.051 × 10⁴ | 20 (12)                          |
|         | (R² = 0.999)         |                               |                                  |
| Br⁻     | 0 – 120              | y = 1.617 × 10x + 0.050 × 10⁷ | 88                               |
|         | (R² = 0.999)         |                               |                                  |
| NO₂⁻    | 0 – 2                | y = 1.684 × 10x – 0.009 × 10⁷ | 0.9                              |
|         | (R² = 0.999)         |                               |                                  |
| NO₃⁻    | 0 – 2                | y = 9.866 × 10x + 0.001 × 10⁷ | 1.9                              |
|         | (R² = 0.999)         |                               |                                  |
| I⁻      | 0 – 1                | y = 2.689 × 10x – 0.005 × 10⁷ | 0.9 (0.3)                        |
|         | (R² = 0.999)         |                               |                                  |

Sample injection volume, 100 μL.
1. ( ), 200 μL.
2. ( ), 500 μL.

Table 3 Analytical results of inorganic anions in seawater samples (n = 3)

| Sample      | IO₃⁻       | BrO₃⁻      | Br⁻        |
|-------------|------------|------------|------------|
|             | Added/ mg L⁻¹ | Result/ mg L⁻¹ | Recovery, % | Added/ mg L⁻¹ | Result/ mg L⁻¹ | Recovery, % | Added/ mg L⁻¹ | Result/ mg L⁻¹ | Recovery, % |
| Hiroshima prefecture |           |            |            |           |            |            |           |            |            |
| Surface seawater 1    | 0         | 0.032 ± 0.003 | –          | 0         | N.D.       | –          | 0         | 63.84 ± 0.18 | –          |
|                        | 0.1       | 0.138 ± 0.003 | 104        | 0.1       | 0.098 ± 0.016 | 98         | 10        | 75.64 ± 0.38 | 103        |
| Surface seawater 2    | 0.1       | 0.021 ± 0.002 | –          | 0.1       | 0.093 ± 0.002 | 93         | 0         | 57.67 ± 0.10 | –          |
|                        | 0.1       | 0.120 ± 0.002 | 99         | 0.1       | N.D.       | –          | 0         | 67.22 ± 0.07 | 100        |
| Shizuoka prefecture   |           |            |            |           |            |            |           |            |            |
| Surface seawater 3    | 0         | 0.061 ± 0.001 | –          | 0         | N.D.       | –          | 0         | 64.06 ± 0.09 | –          |
|                        | 0.1       | 0.157 ± 0.002 | 97         | 0.1       | 0.099 ± 0.005 | 99         | 10        | 73.67 ± 0.07 | 100        |
| Surface seawater 4    | 0.1       | 0.051 ± 0.005 | –          | 0         | N.D.       | –          | 0         | 57.11 ± 0.21 | –          |
|                        | 0.1       | 0.154 ± 0.001 | 102        | 0.1       | 0.099 ± 0.002 | 99         | 10        | 67.19 ± 0.82 | 100        |

| Sample      | NO₂⁻       | NO₃⁻       | I⁻         |
|-------------|------------|------------|------------|
|             | Added/ mg L⁻¹ | Result/ mg L⁻¹ | Recovery, % | Added/ mg L⁻¹ | Result/ mg L⁻¹ | Recovery, % | Added/ mg L⁻¹ | Result/ mg L⁻¹ | Recovery, % |
| Hiroshima prefecture |           |            |            |           |            |            |           |            |            |
| Surface seawater 1    | 0         | N.D.       | –          | 0         | 0.017 ± 0.001 | –          | 0         | 0.017 ± 0.001 | –          |
|                        | 0.1       | 0.094 ± 0.001 | 94         | 0.1       | 0.114 ± 0.004 | 98         | 10        | 0.113 ± 0.001 | 97         |
| Surface seawater 2    | 0         | 0.023 ± 0.001 | –          | 0         | 0.998 ± 0.006 | –          | 0         | 0.022 ± 0.001 | –          |
|                        | 0.1       | 0.120 ± 0.001 | 98         | 10        | 1.102 ± 0.002 | 101        | 0.1       | 0.121 ± 0.001 | 100        |
| Shizuoka prefecture   |           |            |            |           |            |            |           |            |            |
| Surface seawater 3    | 0         | 0.018 ± 0.001 | –          | 0         | 0.526 ± 0.002 | –          | 0         | 0.009 ± 0.001 | –          |
|                        | 0.1       | 0.114 ± 0.001 | 97         | 0.1       | 0.629 ± 0.002 | 101        | 0.1       | 0.104 ± 0.001 | 95         |
| Surface seawater 4    | 0.1       | 0.014 ± 0.002 | –          | 0         | 0.659 ± 0.003 | –          | 0         | 0.010 ± 0.001 | –          |
|                        | 0.1       | 0.115 ± 0.007 | 101        | 0.1       | 0.761 ± 0.002 | 100        | 0.1       | 0.108 ± 0.001 | 98         |

Peak area method was used for determination.
then 45 μg L⁻¹ for IO₃⁻ and 60 μg L⁻¹ for BrO₃⁻ by cycling-column switching IC with UV (213 nm),³³ and three dimensional IC with CD,²² respectively. With 500-μl injection, the DLs for IO₃⁻ decreased to 0.3 μg L⁻¹, which is similar to 0.2 μg L⁻¹ by IC-UV with a concentrator column system (6-ml sample injection).³¹

On the other hand, IC with ICP-MS has a higher sensitivity for BrO₃⁻ and Br⁻ (DLs, 2.0 - 3.0 μg L⁻¹),³⁴ and for IO₃⁻ and I⁻ (DLs, 1.5 and 2.0 μg L⁻¹),³⁵ respectively, except for iodide.³¹,³³ However, matrix ions in seawater might not be suitable to a MS detector. A column-switching IC with CD gave DLs of 8.6, 6.3 and 2.3 μg L⁻¹ for NO₂⁻, NO₃⁻, and Br⁻, respectively, in the chloride concentration of 4000 mg/L.¹¹ t-ITP-CE with UV with a concentrator column system (6-ml sample injection).³¹ IC with CD,¹² respectively. With 500-

and 0.23 μg L⁻¹ for IO₃⁻ and I⁻, respectively.¹⁸ There have been no reports concerning the separation of the six anions in a single run. Our present IC-UV method is simple and robust for the chloride concentration of 4000 mg/L.¹¹ t-ITP-CE with UV with a concentrator column system (6-ml sample injection).³¹ IC with CD,¹² respectively. With 500-

and 0.23 μg L⁻¹ for IO₃⁻ and I⁻, respectively.¹⁸ There have been no reports concerning the separation of the six anions in a single run. Our present IC-UV method is simple and robust for the fast and sensitive determination of the anions in seawater in a single run. Further increases in sensitivity for IO₃⁻ and BrO₃⁻ will be necessary.

Anion separation in seawater

Figure 5 shows the anion separation in surface seawater samples and the samples spiked with IO₃⁻, BrO₃⁻, Br⁻, NO₂⁻, NO₃⁻, and I⁻. Seawater samples were filtered through a 0.45-

μm filter. Good chromatograms were obtained without interferences by matrix ions, such as Cl⁻ and SO₄²⁻. A sample pretreatment was not necessary, except for filtration. The present method is simple, robust and easy to operate. The performance of the IC system was maintained in various studies without any deterioration. Fast and sensitive determinations of the anions with good chromatograms were achieved successively at a rate of 12 min per sample.

Conclusion

Six anions (IO₃⁻, BrO₃⁻, Br⁻, NO₂⁻, NO₃⁻, and I⁻) in seawater were determined in a single IC run without any interferences by matrix ions, such as Cl⁻ and SO₄²⁻. A sample pretreatment was not necessary, except for filtration. The present method is simple, robust and easy to operate. The performance of the IC system was maintained in various studies without any deterioration. Fast and sensitive determinations of the anions with good chromatograms were achieved successively at a rate of 12 min per sample.

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