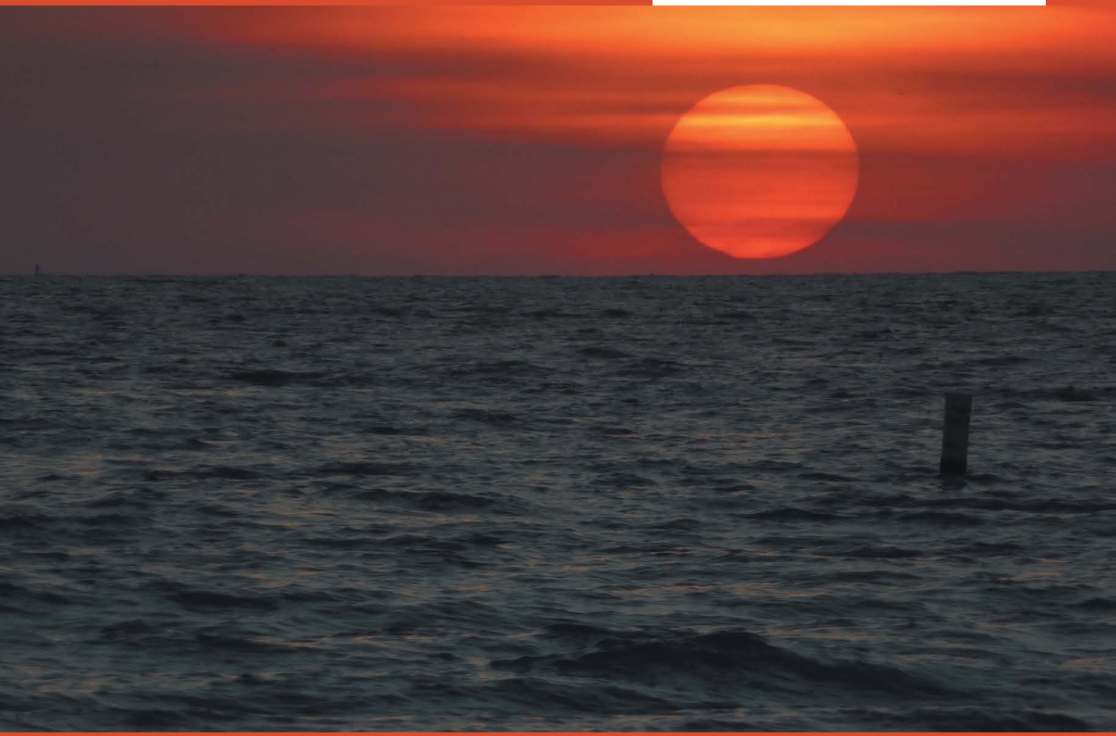

Ion Chromatography

Essential Knowledge Briefings

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WHAT HAPPENS INSIDE MAKES IT SAFE OUTSIDE

Sometimes it's the people we don't see who have the biggest impact on our day-to-day lives, like the IC chromatographers who perform routine analyses that give us the peace of mind to use everyday products and resources without a second thought. The Thermo Scientific™ Dionex™ Integrion™ HPIC™ system was thoughtfully developed around the analysis challenges of modern day laboratories. With a logical, flow-based plumbing layout and remote performance monitoring, it's a reliable instrument made to support you in your mission to protect what matters most.

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COVER IMAGE CAPTION: Ion chromatography helps scientists analyze the quality of environmental water, and many industries—from electronics to pharmaceuticals—use this technology. (Image courtesy of Mike May.)

Prepared for Wiley and Thermo Fisher Scientific, Inc. by EKB Editors, Mike May, Ph.D. and Gary Heebner, Ph.D.

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INTRODUCTION

Ion chromatography (IC)—a form of liquid chromatography (LC)—separates and detects ionic compounds in various samples. This technology is appropriate for a wide range of analytes, including anions and cations, amino acids and peptides, carbohydrates and fatty acids, oligonucleotides and polyphosphates, and more. The results provide the concentrations of the various ions in a sample. A wide range of processes in many industries—including electronics, environmental sciences, food and beverage, pharmaceuticals and more—use IC. For example, public-health offices often use IC to analyze the quality of drinking water and the makeup of waste water.

In general, the process of IC involves six steps:

- the sample, or analyte, is injected into the chromatographic fluid, or eluent
- the analyte-eluent mixture, which is the mobile phase, flows through a column filled with a material—a resin or gel—that is the stationary phase
- sample components dissolved in the mixture move through the column at a rate that is inversely related to how well they bind to the stationary phase
- the fluid moves from the output of the column to a suppressor that reduces the background conductivity of the eluent and increases the conductivity of the analyte, which increases the signal-to-noise ratio of the analyte
- the suppressed analyte-eluent mixture goes to a detector
- the resulting data make up an ion chromatogram.

A wide range of modifications—different eluents and columns, as well as various detectors—can be applied to improve the ability to measure specific ions in a particular sample. For example, different active materials are used for the stationary phase when trying to isolate anions versus cations, because the stationary phase must be positively or negatively charged, respectively.

The data collected depend on the detector, but some features remain consistent. A peak in a chromatogram, for example, usually represents a specific ion (unless there is co-elution), and the area under the peak relates to the ion's concentration in the sample.

IC technology can be applied to a wide range of samples, including fluids and solids, but the kind of sample impacts the required sample preparation. Liquid samples may need only filtration. For solid samples, extraction methods pull the ions out of the sample for IC analysis.

The broad range of potential samples and applications make IC the choice analytical technique in an increasing number of situations. Over time, scientists and engineers have developed technology that makes IC easier to use and more robust, and the improvements continue.

HISTORY AND BACKGROUND

In 1850, the *Journal of the Royal Agricultural Society of England* published an article by agricultural scientist Sir H.S.M. Thompson and chemist J.T. Way in which they reported on ion exchange in soil. In particular, they used clay to extract various ions, including ammonium, calcium and magnesium. That article is often cited as the first ion chromatography.

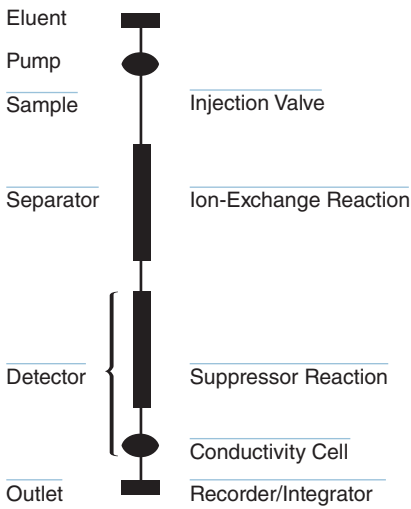
Nearly a century later, in the 1940s, scientists working on the Manhattan Project developed an IC-based technique to collect the nuclear materials used to make the first atomic bomb. Other advances pushed IC technology ahead, and in 1975 scientists from the Dow Chemical Company published a method—now known as suppression—in *Analytical Chemistry* that reduced background noise without reducing the signal from the analytes. This paved the way for industrializing IC. As the scientists wrote: "The demand for the determination of ionic species in a variety of aqueous environments is increasing rapidly and, as a result, there is an expanding need for automated or semiautomated analysis of chemical plant streams, environmentally important waters such as waste streams, rivers, and lakes, and fluids of biological interest such as blood, urine, etc." This suppression technology improved the throughput and sensitivity of IC enough to make it suitable for widespread use.

Advances in columns for IC also improved the results. For example, high-pressure IC (HPIC) uses smaller-size particles in the columns, leading to faster, higher resolution and more reproducible experiments. The smaller particles create sharper peaks that can separate analytes more completely—especially ones that elute similarly, such as acetate and lactate—while increasing the necessary pressure tolerance of the system. In addition,

decreasing the diameter of the column, say from a 4 to a 0.4 millimeter inside diameter, can increase an IC's mass sensitivity by 100 times.

Getting that sensitivity, though, also arose from improvements in suppression technology. As is briefly noted above, a suppressor reduces the electrical conductivity of the eluent and increases the analyte's conductivity. This technology started to emerge at the Dow Chemical Company in the early 1970s. It consisted of placing an additional column after the one used for separation. It was first called the stripper column because it "stripped" the effluent of highly conductive elements, leaving just the analytes in water or another low-conductance solution.

In 1991, Dionex Corporation released its MicroMembrane Suppressor, which brought rugged and robust suppression, even for



A basic ion-chromatography system combines a sample with an eluent and processes the mixture for analysis by a detector. (From: Weiss J. 1995. *Ion Chromatography, Second Edition.* Bern, Germany: Wiley-VCH.)

high concentrations of eluent. Despite the advance of this suppression technology, users needed continuous chemical regeneration (a separate acid or base solution). Because of this, Dionex developed its Self-Regenerating Suppressor. Today, scientists and engineers can choose from various forms of suppression that can be tailored to a specific IC application—all designed to work with the complete setup, including the analytes, composition of the matrix, the eluent and so forth.

In fact, changes in the eluent have also improved IC. Scientists at the Dow Chemical Company—from which Dionex purchased licensing agreements in the early 1970s, before Dionex was purchased by Thermo Fisher Scientific in 2010—first used dilute hydrochloric acid as the eluent for cations. For anions, scientists used carbonate eluents that turned into weak carbonic acid; many applications relied on this procedure for years.

In 2003, Reagent-Free Ion Chromatography (RFIC) made everything easier. This version of IC uses electrolysis of deionized water and a cartridge that contains the necessary eluent counterion to produce the eluent. With RFIC, the analyst doesn't need to make or add eluent. Instead, the analyst simply needs to specify the required concentration in the chromatography software. Beyond making IC easier and more efficient, RFIC can also improve the reproducibility and sensitivity of measurements, as well as reduce errors that can come with making the eluent by hand.

Some samples prove more difficult to work with than others, and special methods can be the most effective in some cases. For carbohydrates, for example, high-performance anion-exchange chromatography with pulsed amperometric detection (HPAE-PAD) is often used. This technique combines a separation technique, HPAE, with a specific form of detection, PAD. In HPAE, an anion-exchange

material in the stationary phase and a hydroxide-based eluent at high pH separate the carbohydrates, which are weakly acidic. HPAE uses nonporous polymeric resins in the stationary phase, which produce sharper peaks and better separation of the carbohydrate components.

With PAD, controlling electronics change the voltage applied to a working electrode in a rapidly repeated sequence of pulses. Analytes oxidize on the electrode's surface, which creates a current that can be measured by the electrode. This detection is sensitive enough to detect analytes in pico- and femtomolar concentrations. HPAE-PAD separates carbohydrates by charge; for carbohydrates with the same charge, it can also separate them by size and other features. For even better separations, HPAE-PAD can be combined with HPIC columns. Scientists can also use columns designed to separate specific classes of compounds, like monosaccharides and oligosaccharides.

As IC technology grows more specialized and sophisticated, even government regulations have expanded to include the technology. For example, the U.S. Environmental Protection Agency (EPA) developed its Method 314.0 for measuring perchlorate in water with IC.

This is only one of today's many regulations that requires IC, and more will surely be developed. In addition, advances in the technology help more scientists and engineers apply IC, and the following examples provide some sense of the breadth of this technology in analyzing a wide range of samples for different purposes.

IN PRACTICE

The breadth of potential applications of IC—from environmental and industrial, including tracking pollution and manufacturing a wide range of products, to foods and medicine, including the detection of contaminants and developing safe treatments—demands a variety of adjustments and fine-tuning to various elements of the IC platform. As is explained above, the evolution of IC makes it easier to use and more robust. Many applications benefit from these past improvements. In some cases, other improvements are required, such as changing the upstream separation technology or using different IC columns. In other cases, adding automation makes IC work better in specific applications, especially ones that require higher throughput. Likewise, stretching the areas of use for IC also arises from simplifying the operation and interpretation for the user, but reducing the knowledge and experience required to use the system requires the creation of software that does the computational heavy lifting and analysis.

Like many other forms of analysis, IC can be adapted, often in relatively simple ways, to handle the specific requirements of even a very defined application. In addition, advances made with one application can benefit another. Thus the more that scientists and engineers explore the uses of IC in various experimental and applied situations, the more it can be used across all of science and technology.

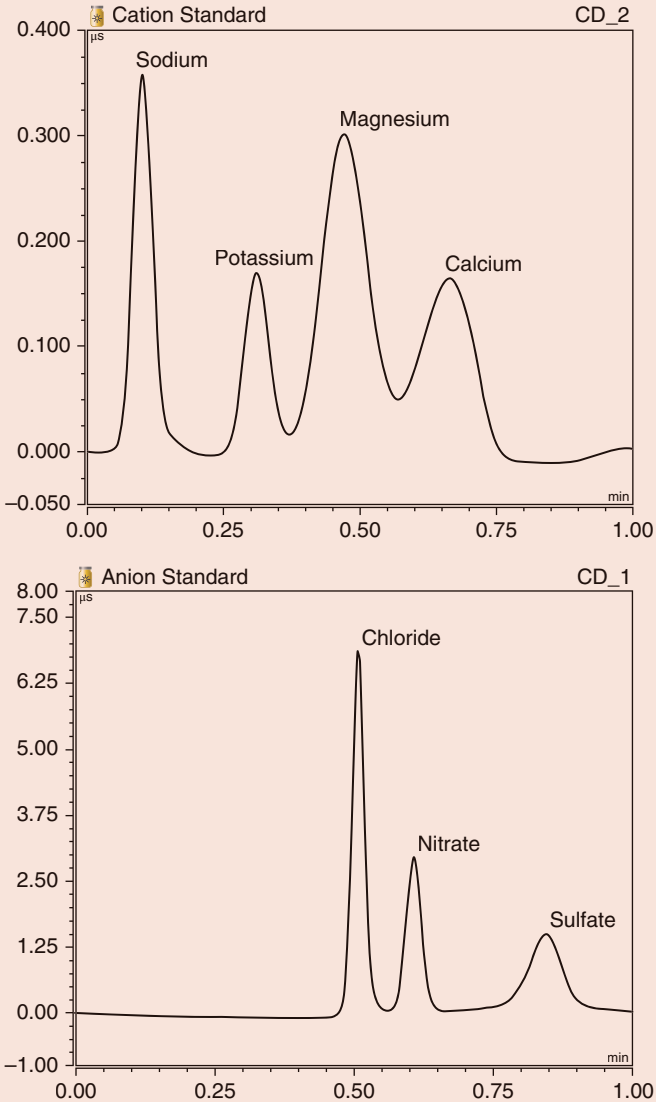
The following case studies portray several specific uses of IC.

CASE STUDY ONE

Ice around the world freezes moments in time—sometimes moments that are hundreds of thousands of years old. To "read" that history, scientists take cores from glaciers and ice sheets, such as those in Alaska, Antarctica and Greenland. The cores can be up to 3,000 meters long, and the captured chemistry records the history of the Earth's climate, as well as pollution in past atmospheres. Given the difficulty in collecting such samples, scientists want to extract as much information from them as possible. At the Dartmouth Ice Core Lab at Dartmouth College in Hanover, New Hampshire, director Erich C. Osterberg and manager David Ferris use the smallest sample sizes possible in ice-core analysis. This analysis relies on IC, and different ions are used for different information. For example, scientists analyze sulfate concentrations to track volcanic eruptions. To simplify the workflow, Osterberg and Ferris use RFIC systems.

In addition to limiting sample size, the researchers require fast processing, because the facility analyzes about 400 samples each day, and each is run through cation and anion analysis. Using an HPIC capillary system, the scientists rapidly capture data on trace elements even when using microliter sample sizes. In fact, this system improved the limit of detection by an order of magnitude.

To process so many samples, Osterberg and Ferris run as many as eight IC setups, and a system that creates its own eluent comes in handy. As Ferris says, "Having to make and adjust eluent for eight ICs consumed one day per week. Using RFIC systems, this time is used for analysis." He adds, "The RFIC system also makes developing and fine-tuning a method much easier and faster."



Ice-core samples processed with cation separation using the Thermo Scientific Dionex IonPac CS12A column *(top)* and anion separation using the Thermo Scientific Dionex IonPac AG11-HC guard column *(bottom)* show component separations in just one minute. (Images courtesy of Thermo Fisher Scientific.)

Therefore in analyzing ice cores for changes in climate or pollution over hundreds of millennia, RFIC systems reduce sample size, improve sensitivity and save time.

https://tools.thermofisher.com/content/sfs/brochures/CS-71316-IC-Dartmouth-Ice-Core-CS71316-EN.pdf

CASE STUDY TWO

The fermentation of cereal or cassava to make alcoholic beverages also produces cyanide. This deadly chemical inhibits cytochrome C oxidase, which blocks cellular respiration. Drinking-water standards limit cyanide to very low levels, just 50 micrograms per liter (µg/l) in the European Union. Nonetheless, no simple method determines cyanide levels in alcoholic beverages. In the past, scientists used spectrophotometry, titration and other methods, and spectrophotometry is considered the classic technique. Scientists from the Chengdu Institute of Product Quality Inspection Company and the Chengdu Product Quality Supervision and Inspection Institute in China sought a better method.

This team wanted to measure free cyanide in alcoholic beverages with IC, although other research teams indicated challenges—including high noise and poor reproducibility—with traditional methods. Consequently, the Chinese team tried IC-PAD, writing: "Our study focused on the application of IC–PAD to achieve the rapid measurement of free cyanide in liquor by optimising factors such as eluent concentration, interferent evaluation and method performance."

The research team used HPIC, plus an eluent generator and an electrochemical detector. With simple sample preparation—a 1:100 dilution and filtration—the scientists reported a linear range of 1–5,000 µg/l, with an r value of 0.9998. They compared results from IC-PAD and the classical spectrophotometric method, and they found that "the data show that the analysis results are in good agreement." They also found that this technique provides the necessary level of sensitivity

even in samples that include components that interfere with the IC-PAD measurement. They concluded: "The optimised IC–PAD is more advantageous than the spectrophotometric method and may have potential applications in liquor analysis."

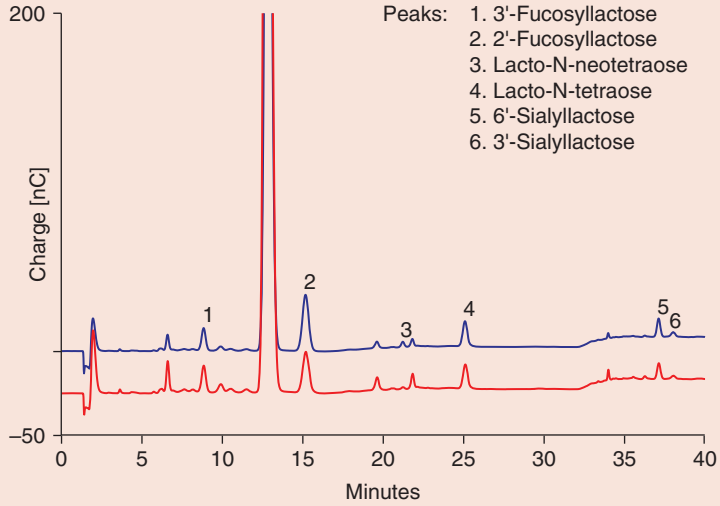
[*Food Chemistry*, 2015, **172**, 681–684 (DOI: 10.1016/j.foodchem.2014.09.052)]

CASE STUDY THREE

More than 130 human milk oligosaccharides (HMOs) have been identified in breast milk, and these molecules are diverse in structure. After lactose and lipids, HMOs make up the third largest component of human breast milk. Some research indicates that these HMOs drive immunomodulatory and anti-infective mechanisms. Nonetheless, the specific HMO profile varies among individuals—based on genotypes, ethnicity and even if the labor developed pre- or full-term. Furthermore, the HMO levels in breast milk vary over time, starting at the highest levels and decreasing over the course of lactation.

To study the effects of HMOs, scientists need accurate and efficient methods of identifying and quantifying them. Typically, this involves high-performance anion-exchange chromatography with PAD. To improve the sensitivity, sample preparation usually involves removal of the lipids and proteins through centrifugation, filtration or gel-permeation chromatography. To accelerate and simplify this process, scientists from Abbott Nutrition Research and Development and Thermo Fisher Scientific developed a method that bypasses sample derivatization. By adding a polymeric reversed-phase column, which removes hydrophobic contaminants, the sample can be diluted and injected into the instrument.

They validated this technique on six HMOs—2′-fucosyllactose, 3′-fucosyllactose, 3′-sialyllactose, 6′-sialyllactose, lacto-N-tetraose and lacto-N-neotetraose—with detection limits of 4–21 µg/ml. Moreover, this technique provided quantification limits of 13–68 µg/ml. Consequently, this technique covers the variability of HMOs that exists in breast-milk samples, and provides increased throughput with decreased labor.



Chromatograms of a breast milk sample *(red)* and one spiked with human milk oligosaccharide (HMO) standards *(blue)* show the accurate analysis of the HMOs in the sample. (Image courtesy of Thermo Fisher Scientific.)

http://tools.thermofisher.com/content/sfs/brochures/CAN-119-IC-HPAE-PAD-Oligosaccharides-Human-Breast-Milk-CAN71799-EN.pdf

CASE STUDY FOUR

Fluoride can be dangerous when too much is consumed. Consequently, regulators impose fluoride limits in foods. For example, the U.S. Food and Drug Administration (FDA) recommends an upper limit of 100 milligrams of sodium fluoride per 100 kilograms of food. The largest source of animal protein in the world comes from Antarctic krill, but it contains high levels of fluoride. Quantifying these levels requires specific techniques because krill contain free and bound forms of fluoride. Although the fluoride can be quantified with gas chromatography, high performance liquid chromatography, ion chromatography, an ion selective electrode (ISE) or spectrophotometry, a group of scientists from the Chinese Academy of Fishery Sciences and Shanghai Ocean University selected IC for its speed, selectivity and sensitivity.

Specifically, this group used an IC system that included a continuously regenerated trap column, a self-regenerating suppressor and a conductivity detector. An anion-exchange column provided separation upstream of the IC. As the scientists wrote: "The aim of this study was to establish a valid qualitative and quantitative method for fluoride in Antarctic krill."

The presence of fluoride in free and bound forms creates the biggest difficulty. The scientists solved this challenge with pretreatment that dissolved the fluoride into its water-soluble, ionic form. After testing four pretreatment methods—double-deionized water extraction, sulphuric-acid distillation, hydrochloric-acid extraction and pH adjustment with buffer—they concluded that "sulphuric acid distillation was suitable preparation for ion chromatography determination of fluoride in Antarctic krill." Moreover, this technique provides a linear

range of 0.1–10.0 mg/l and an r value of 0.99998. As they wrote: "Our results indicate that the method (limit of quantification 0.2 mg/l) could be well applied for the determination of fluoride in Antarctic krill."

[*Czech Journal of Food Sciences*, **2015**, **33**, 77–82 (doi: 10.17221/498/2013-CJFS)]

CASE STUDY FIVE

The manufacturing of fuel injectors in modern diesel engines must adhere to tight tolerances. As a result, fuel contamination becomes a problem. For example, precipitation and sodium salts in injectors can mechanically block them. The sodium salts can come from catalysts used in producing biodiesel, drying agents, pipelines and several other sources. To detect sodium in diesel fuel, engineers can use inductively coupled plasma–optical emission spectrometry (ICP-OES), which typically provides a lower detection limit of about 0.1 parts per million. Engineers can get even better results with ICP-mass spectrometry (ICP-MS), but few researchers have access to this technique. Given this, scientists from Daimler and Thermo Fisher Scientific wanted a direct method that is widely available to determine sodium in diesel, biodiesel and other fuels.

Liquid-liquid extraction is required to isolate sodium prior to IC. Nonetheless, it takes some effort to find the best liquid to use when extracting the fuel, and these extractions take more time than is desired in most applications. Because of this, the Daimler–Thermo Fisher Scientific team wanted an automated, cost-effective and fast method that is 10–100 times more sensitive than the ICP-OES method.

To meet those goals, the team used an RFIC system with a self-regenerating suppressor and a conductivity detector. In addition, a concentrator column retained the sample's cations and removed the hydrophobic matrix, which is crucial to analyzing a sample, like diesel, that is immiscible with water.

To validate the method, the scientists compared the IC results with those from atomic absorption spectrometry and ICP-OES. They

found comparable results with all three methods, and the IC method proved very sensitive, with a limit of detection in the sub-µg/l range and high reproducibility. Consequently, this approach met the goals and dramatically simplified the methodology. In addition, the use of software developed specifically for managing and analyzing chromatography further simplified the use of IC in this application.

http://www.dionex.com/en-us/webdocs/115361-CAN-118-IC-Trace-Sodium-Diesel-Biodiesel-Fuel-AN71197-EN.pdf

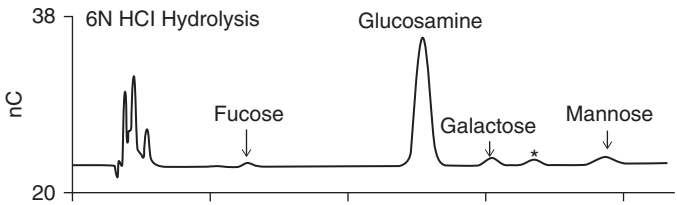
PROBLEMS AND SOLUTIONS

Like so many of today's laboratory methods, IC faces constant pressure to do more and to do it faster. In some systems, higher pressure leads to higher throughput. For example, combining high-pressure capable RFIC systems and super macroporous, 4-micron particle size columns can provide high performance and fast run times. Such columns come in various lengths, such as 150 and 250 millimeters. As added benefits, using a capillary system—one with 0.4 millimeter inner diameter columns—reduces the amount of eluent used and the waste produced. Such a system also works with smaller sample sizes.

As the makeup of an HPIC system shows, various components interact to create the best results. Such a synergy also emerges in the pursuit of lower detection limits with IC. As described above, using a suppressor improves the signal-to-noise ratio in IC systems, and that improves the detection limit. That limit also depends on the detector being used.

With IC, several methods of detection can be implemented, including conductivity, electrochemical, photodiode arrays, MS and others. The best choice depends on the analyte being measured. With a conductivity detector—mentioned in examples above—the user gets high sensitivity across a range of analyte concentrations. This type of detector also provides low-noise signals, especially if it includes advanced electronics. Vendors create versions that work with standard and capillary IC, and some come with snap-in connections that require no tools for installation or replacement. Some conductivity detectors also integrate seamlessly with specific chromatography data systems.

Electrochemical detectors for IC can also be used with standard and capillary systems. As described above, HPAE-PAD provides one form of electrochemical detection, and this type of detector can also be used without pulsing the potential—that is, using a direct current (DC) system. When using PAD, some electrochemical detectors come with easy methods of customizing the waveform of the pulses. Like a conductivity detector, today's electrochemical detectors can come with integrated electronics that minimize the noise and maximize the signal, which combine to provide improved sensitivity. Improved thermal stability in conductivity and electrochemical detectors also improves the sensitivity, because the signal doesn't drift due to temperature changes during an experiment.



HPAE-PAD analysis detects human IgG monosaccharides. The asterisk shows the peak for glucose, which often contaminates monosaccharide analysis. (From Rohrer JS. 2012. Monosaccharide analysis of glycoproteins by high-performance anion-exchange chromatography with pulsed amperometric detection. In *Applications of Ion Chromatography for Pharmaceutical and Biological Products, First Edition.* Hoboken, NJ: John Wiley & Sons, Inc.)

IC systems can also include optical-based detectors, such as a photodiode array. These detectors can be used across a wide range of wavelengths—such as the ultraviolet through the visible spectra—and

some provide simple wavelength adjustments, which can be used to improve the signal from specific samples. Some optical-based detectors for IC also increase the signal absorbed, improving the sensitivity.

Some other forms of detection, which also improve the sensitivity of IC measurements, will be discussed below.

The complexity of a sample also complicates IC analyses, and expanding the use of this technology forces users to work with samples that come in increasingly complex matrices. Almost any sample of the Earth's crust, for instance, contains aluminum, and it is also used in a wide range of products, including cosmetics and medications, both prescription and over-the-counter. Aluminum is also used in different forms, such as aluminum chloride, aluminum chlorohydrate and aluminum zirconium octachlorohydrate. Depending on the products, regulators often limit the amounts of these forms of aluminum. To measure the forms of aluminum in various products, scientists face different matrices, and regulators often require different assays for different products. For example, the United States Pharmacopeia requires different assays and analytical techniques, such as various forms of chromatography, including IC. To improve the results of such tests, some vendors provide methods for IC system-column combinations that come with valuable features, including separating aluminum from matrices composed of various components.

In much of science and seemingly all of industry, analytical techniques must test samples more thoroughly and faster than ever. Also, the difficulty of the tests often increases with requirements to analyze samples in more complex matrices and to provide more information to regulators. All combined, this escalates the demands on the instrument operators. In addition, ICs are often found in laboratories where the operator is not an expert on the technology,

particularly the science behind it. In short, this requires IC systems that are easier to use and more robust. Some of the features already discussed meet these needs. For instance, RFIC systems require less maintenance and are easier to use—just add water and the IC platform does the rest. Some systems include other features that simplify use, such as a tablet that can be used to interact with the device from a distance or a user interface that keeps track of the system's performance and maintenance needs. Some of today's detector systems also last longer, which contributes to reduced maintenance. Also, a sophisticated data system ensures repeatability and simplicity, all while collecting, storing, protecting and analyzing the data.

As these examples show, the advances in IC keep up with the needs of the various fields that use this technology and how they use it—often dependent upon the requirements of regulators. Nonetheless, increasing demand for sensitivity, throughput and dealing with complex samples and matrices requires even more advances in the technology. Some of the key improvements are described in the following section.

WHAT'S NEXT

Changes in scientific and industrial areas of interest also impact uses of technology. For example, metabolomics studies metabolites, and many scientists analyze these samples with reversed-phase LC plus MS. Nonetheless, this form of LC-MS fails to separate some of the key metabolic components, including nucleotides, organic acids and others compounds. In particular, metabolomics scientists need ways to distinguish isomeric metabolites, or ones with the same formula. That can be accomplished with IC-MS.

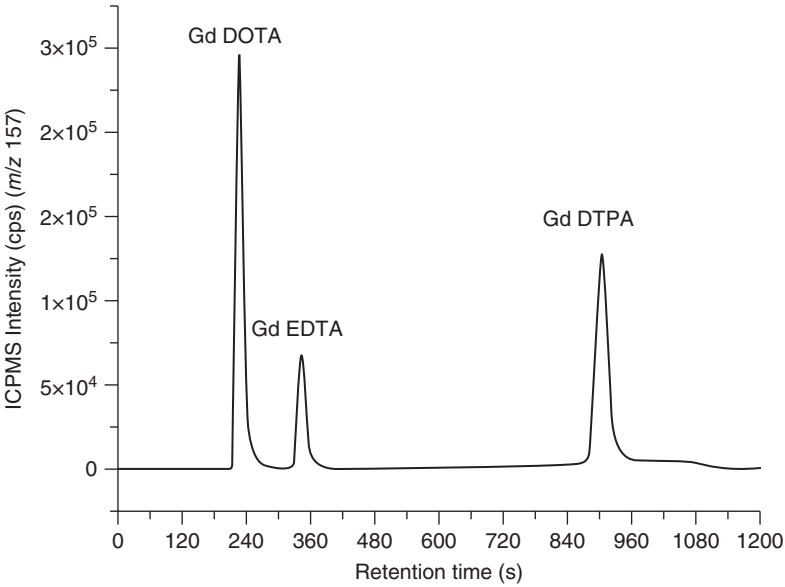
IC separates the metabolic components that reversed-phase LC doesn't, such as organic acids. By including eluent suppression in IC, the separated samples can be analyzed with MS. Without eluent suppression, the high concentration of salt in the sample prevents the use of MS for detection. With eluent suppression, IC-MS provides high sensitivity in identifying metabolites. Moreover, the liquid eluted from IC is highly polar, which makes it work well with electrospray ionization. Leaders of labs and companies can buy commercial systems that combine IC and MS. This will fuel the spread of this technology to analytical areas beyond the possibilities for metabolomics. For example, IC-MS has been shown to effectively analyze organic acids in various applications, including agricultural chemicals, beverages and environmental waters. IC-MS has also been used to analyze carbohydrates. In fact, even though IC-MS offers so many benefits to metabolomics studies, it remains largely unexplored in this area. Samples from metabolomics come in complex matrices that IC can handle, and the broad collection of metabolites, including isomeric ones, can be identified and quantified with IC-MS. These benefits offer

opportunities through research and development, as well as in manufacturing, that will enhance many industries, such as drug discovery in the pharmaceutical industry.

IC can also be used upstream of other forms of MS, such as ICP-MS. This technology came on the market in 1983, and scientists use it for many applications, especially when analyzing rare-earth elements in geochemical labs. ICP-MS provides improved detection and throughput when compared to related forms of analysis, such as graphite-furnace atomic absorption spectroscopy. ICP-MS can also be used with samples in a range of matrices, from simple to complex.

IC-ICP-MS is especially useful in speciation, which analyzes the chemical forms, or species, of an element. For example, arsenic can be found in various organic and inorganic forms. The inorganic forms—arsenate and arsenite—are highly toxic, but some of the organic forms—like monomethyl and dimethyl arsenic—are not nearly as toxic. Similar collections of species exist for other elements—including copper, mercury, selenium and others—and this complicates the analysis of samples, especially determining the likely chemical or biological behavior of a sample's components. With IC-ICP-MS, analysts get the speciation information that can be used to distinguish and quantify toxic and nontoxic components. IC-ICP-MS systems are available, and include integrated software for analyzing the speciation of metals.

The outcome of IC-based testing also depends on the sample preparation. For many samples, preparation for IC requires simply diluting the sample with deionized water. Some samples require more intensive treatment, such as filtering or removing contaminants in some way to improve the level of detection. The best approach to preparing a sample, though, should be easy, reproducible and not



Using an anion-exchange column, IC-ICP-MS detected gadolinium (Gd) complexes. (From: Mattusch J. 2016. High-performance liquid chromatography coupled to inductively coupled plasma MS/electrospray ionization MS. In *Application of IC-MS and IC-ICP-MS in Environmental Research, First Edition.* Hoboken, NJ: John Wiley & Sons, Inc.)

damage the key components of the sample. With some samples—like plastics and printed circuit boards, petroleum products and ores—the standard preparation methods fail or at least make it difficult to analyze the components. In those cases, combustion IC heats the sample to 1,000 degrees Celsius for a few minutes in an air or oxygen stream, which turns the sample—solid, liquid or gas—into a vapor that is then dissolved into a solution that goes directly into the IC.

Many environmental applications require analyzing air. For instance, industrial or automotive emissions contain volatile ionic components that can increase the acidity of rain when these particles dissolve in the precipitation. Air sampling can be connected with

IC. Systems are available that continuously collect air samples and dissolve them in water for analysis by IC. Some systems can even collect and analyze the air samples over multiple days without any user interaction. This can be especially useful in remote areas where environmental monitoring is required.

That walkaway capability is not needed for all uses of IC for sample analysis, but the evolution of this technology—such as eluent suppression and RFIC systems—keeps making it easier to use. In addition, advances in the user interface and analytical software allow less experienced operators to run today's IC systems and apply the results. That trend toward ever-easier operation is likely to continue, and that will push IC analysis into even more applications.

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