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Ion chromatography

Developing an ion chromatography system

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Introduction

Ion chromatography (IC) has become essential for analyzing ionic and small polar compounds. It has been applied in many areas, ranging from the analysis of drinking water, food and beverages, and cooling water to lithium-ion battery research, process quality assurance, and the presence of corrosives in liquified petroleum gas.

IC can trace its origins to work done at what would become Dionex Corporation in the mid-1970s with the introduction of the first ion chromatograph in 1975, the Dionex™ Model 10 IC system. This system had the essential elements of an IC system: a pump, separating column, eluent suppressor, conductivity detector, and data recorder (Figure 1).

This basic system provided adequate data, but several factors restricted sample throughput and required a considerable investment in labor and significant expertise to maintain. Column capacity and packed bed suppressor capacity were limited, and the instrument configuration was inflexible, constraining the type of samples that could be analyzed. Offline suppressor column regeneration was needed, the pressure tolerance was low, and the background conductivity was comparatively high. Furthermore, manual peak integration was required, eluent usage was significant, and there was substantial run-to-run variability. Since the Dionex Model 10 IC system, many innovations have been developed and incorporated into new systems to address these deficiencies. Additional advancements have enhanced robustness, reliability, user-friendliness, functional flexibility, and integrated data analysis. Ideally, an ion chromatograph will meet current customer demands while being adaptable to address potential future analytical needs.

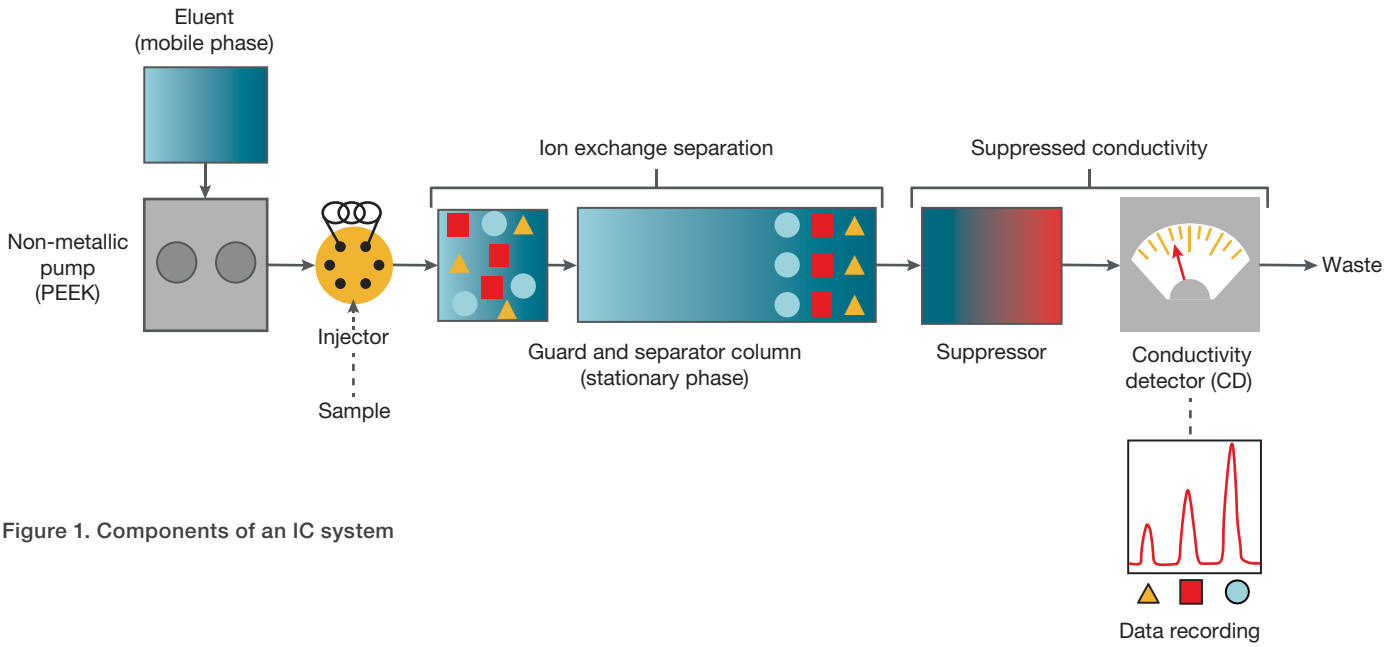

Figure 1. Components of an IC system

Technical innovation

Innovation is key to meeting the demands of new applications, complex matrices, and low detection limits, all while minimizing the time and effort required for instrument operation and maintenance.

Thermo Fisher Scientific, as the innovation leader in IC, has introduced key advances in technology that include:

- **Reagent-Free™ IC (RFIC™) -** By applying a precisely controlled electric current during water electrolysis, a high-purity eluent, such as potassium hydroxide, can be automatically generated in an Eluent Generator. After facilitating the separation of ions in an ion exchange column, the electrolytically generated eluent can be suppressed into a low conductive form, such as water in the case of KOH eluents. To cover advanced applications such as complex carbohydrates, the option to use two eluent generator cartridges in series exists to produce the potassium hydroxide/potassium methanesulfonate mixtures required for elution. RFIC systems avoid routine exposure to hazardous chemicals while increasing operator-to-operator consistency, removing another variable affecting results. Electrolytically generated gradients enable precise control of the separation of complex mixtures.[1]

- **Electrolytic suppression -** Suppression is one of the critical processes in an IC system. This involves chemically converting the eluent into a less dissociated form and the analytes into a more dissociated form. This results in a sensitive and gradient-capable detection method known as "suppressed conductivity detection." Unless the suppressor, the device in which the suppression reaction takes place, is regenerated, its long-term operation is compromised due to exhaustion. Continuous electrolytic regeneration is the current state-of-the-art technology, ensuring a high and dynamic suppression capacity. In its most popular configuration, the recycled, neutralized eluent is the source of *in situ* electrolytically generated regenerant ions. The practical benefits of electrolytic regeneration include uninterrupted continuous operation, application flexibility, and labor savings from not preparing potentially hazardous chemical regenerant solutions manually.[2]

- **Column properties -** The three areas that have undergone development are 1) porosity to increase ion-exchange capacity, 2) selectivity to optimize the relative elution order of specific analytes, and 3) smaller particle size to increase efficiency and chromatographic resolution. Columns packed with smaller particles (i.e., 4 µm) can be shorter and use higher flow rates, decreasing analysis time while maintaining chromatographic resolution.[3]

- **High-pressure tolerance -** The development of stationary phases with ever smaller separation particles (e.g., 4 µm) required the development of high-pressure pumps and related consumables. Standard-length columns (250 mm) used at their recommended flow rate (0.25 or 1 mL/min for 2- or 4-mm inner diameter columns, respectively) can achieve high-efficiency separations with moderate runtimes. Due to the smaller particle size, higher system backpressures result. Modern metal-free IC pumps and consumables (such as eluent generation cartridges) are designed to tolerate back pressures of up to 5,000 psi for RFIC configurations.

- **Finger-tight connections -** Low-dead-volume connections are critical for optimum chromatographic performance in analytical systems. Standard PEEK tubing with bolts and ferrules can be challenging to connect without creating extra void volume, affecting peak resolution and quantification. Manually cut PEEK tubing may have uneven edges, making a flush connection difficult. Conventional PEEK tubing connections are typically tightened with a wrench; if done with too much strength, the material can be damaged. Thermo Scientific™ Dionex™ IC PEEK Viper™ fittings solve these issues by offering finger-tight, pre-cut connections that guarantee a consistently flush fit with minimal dispersion volume.[4]

- **Component layout optimization -** Optimizing the component layout is an effective way to enhance chromatographic separations. This is achievable by logically arranging components and reducing the length of tubing between sample injection and detection. Additionally, connections must be easily accessible, making routine maintenance simpler. This is particularly difficult when maintaining a small benchtop footprint.

Functional adaptability

A versatile, easily upgradeable platform with fundamental capabilities for chemical suppression and manual eluent preparation lays a solid foundation for accurate anion and cation determinations across diverse samples and matrices. The ability to upgrade such a system to keep up with changing workflows avoids the need to purchase new equipment each time this occurs, contributing to its cost-effectiveness and efficiency. In addition, performing these modifications on-site minimizes interruptions to laboratory operations. Significant system upgrades include:

- **Vacuum degas** removes dissolved gas from the eluent, leading to a smoother baseline that facilitates peak integration, improving the analytical performance and overall instrument sensitivity.

- **Electrolytic suppression** eliminates the need for an external regenerant solution, like sulfuric acid or amines, by recycling the suppressed eluent.

- **Eluent generation** boosts lab productivity by eliminating manual eluent preparation, following the design motto, "Just Add Water," while increasing method reproducibility, sensitivity, and transferability. It also enables the use of electrolytically generated gradients for method optimization.

IC systems can be further enhanced with accessories that are, ideally, integrated into the chassis, installed without specialized tools, and automatically recognized by the system software for immediate use. These can include:

- **Column heater** for high run-to-run consistency, reducing the impact of laboratory temperature changes.

- **Digital pressure regulator** for precise pneumatic delivery of chemicals used for suppressor regenerants or post-column derivatization.

- **Peristaltic pump** for simplified solvent or regenerant delivery.

- **Seal wash pump** to flush the main pump seals with deionized (DI) water and avoid formation of precipitated salts from manually prepared eluents, maintaining pump performance and pump seal longevity.

- **10- or 6-port auxiliary valve** to automate IC sample preparation (e.g., dual filters with backflush[5] or inline removal of matrix interference[6]) or column switching, reducing hands-on time.

- **Low-pressure valve** to control the dispensing of pneumatically supplied solvents or switch between bottles, for example.

- **Eluent monitoring** for a visual indication that solutions are getting low, which alerts users to take action and avoid the potential damage and lost time that can occur if the system runs dry.

Integrated data analysis

Computer software revolutionized the control of chromatography systems and enabled numerous options to streamline and automate data analysis processes. Thermo Scientific™ Chromeleon™ Chromatography Data System (CDS) software is the industry standard for automating and optimizing daily tasks and is suitable for compliance-heavy environments.

Here are some user issues that Chromeleon CDS addresses:

- **Increasing system uptime -** System-suitability and self-diagnostics can detect potential hardware or consumable issues at startup so the user can take action and avoid lost time.
- **Getting new methods running quickly -** eWorkflows™ provide easy software import for application-specific methods, processing, and report files.
- **Streamlining system setup -** Autoconfiguration enables the software to recognize and present the appropriate controls for new components.
- **Reducing time to results -** Smart startup and shutdown options allow an instrument to be started again with minimal equilibration time, even after a prolonged idle period.
- **Quickly analyzing data -** Cobra peak detection algorithm automates and guides refinement of peak integration parameters.[7]
- **Ensuring compliance -** Secure audit trails with timestamps, user access and permissions controlled by administrators, electronic signatures, and data versioning are all essential Chromeleon CDS tools for meeting compliance requirements.[8]

The Thermo Scientific™ Dionex™ Inuvion™ ion chromatography system (Figure 2) is the culmination of the technological innovations and attributes described above. It is the ideal solution for laboratories that require the analysis of ionic and small polar compounds. Smart, function-driven design allows quick and safe access to everything on the instrument, and automated startup and shutdown routines ensure the system is quickly ready for the day's work without user intervention. Ultra-reliable performance is achieved with advanced high-performance pump technology and electronics that let users take advantage of a wide range of columns and chemistries to improve the speed and quality of results. It is a versatile, adaptable platform that can be precisely configured for today's needs and budget while providing confidence that it will also be able to meet future requirements. Compared to the other IC systems in the Dionex portfolio, the Dionex Inuvion IC system stands out for its functional adaptability, component accessibility, and compactness (Figure 3).

Figure 2. The Dionex Inuvion IC systems

Attribute	Dionex Inuvion Core	Dionex Inuvion	Dionex Integrion	Dionex ICS-6000
Functional adaptability	●	◕	◑	●
Compactness	●	●	◕	○
Component accessibility	●	●	◕	◕
Feature				
IC PEEK Viper fittings	●	●	●	●
IC Sample preparation	◑	◕	◕	●
Electrolytically regenerated suppressor	○	●	●	●
Vacuum degas	○	●	●	●
Eluent generation	○	◑	◑	●
Gradient separations	○	◑	◕	●

Attribute/Feature: Full functionality supported ● Not present ○

Figure 3. Comparison of Dionex IC systems

Summary

Thermo Fisher Scientific has been an IC leader since the technique's creation, and the Dionex Inuvion IC system represents a significant milestone in pursuit of the ideal ion chromatograph by providing cutting-edge technology that enhances the quality of results and simplifies operation. Consistently reliable performance is achieved by ensuring optimal connections with Dionex IC PEEK Viper fittings, incorporating eluent generation to eliminate operator-to-operator variability and to extend pump life for greater robustness, and maintaining system uptime with suitability tests and self-diagnostics. Despite its compact size and extensive list of capabilities, ease of use is not compromised. System components are logically and optimally arranged to reduce extra column volume while providing unhindered access. Electrolytic suppression eliminates another manual step while increasing lab safety. User-installable accessories that require minimal effort to incorporate can significantly enhance productivity and system performance. Software-based tools such as autoconfiguration, smart startup and shutdown, peak integration with intuitive control, eWorkflows to transfer analytical protocols, conditions, reports, interactive control charts, and tailored system suitability tests expedite data collection and improve user experience.

Conclusion

The progression from the Dionex Model 10 IC system to the sophisticated Dionex Inuvion IC system highlights the significant advancements that have been made in the field of IC. These advancements have not only addressed previous limitations but also introduced new features and capabilities that significantly enhance the performance, reliability, and user-friendliness of IC systems. As a result, the Dionex Inuvion IC system represents the current pinnacle in the ongoing development of IC technology, setting a new standard for what can be achieved in the analysis of ionic and small polar compounds.

The Dionex Inuvion IC system is the result of state-of-the-art techniques and processes used to manufacture, design, and optimize essential hardware components such as pumps, instrument electronics, range-free detectors, and conductivity cells. This integration of advanced technology has resulted in a system that is not only reliable and robust but also flexible and user-friendly.

As we look to the future, the field of ion chromatography will continue to evolve with new challenges and opportunities on the horizon. The Dionex Inuvion IC system is well-positioned to meet these challenges, providing laboratories with a reliable and efficient solution for their analytical needs. In conclusion, the Dionex Inuvion IC system represents a significant achievement in ion chromatography, solidifying Thermo Fisher Scientific's position as a leader in the industry.

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