Advancing GC×GC through Integrated Sample Preparation Methods and Optimized Column Formats

D. Peroni

Summary

Gas chromatography (GC) is one of the separation techniques that encountered the most widespread success thanks to its very high efficiency and good reliability. Nowadays GC a is well-established, mature methodology that is routinely applied to a huge variety of samples in many different fields. With the application range becoming broader, the samples of interest have become increasingly more diverse and complex. As a consequence the importance of the sample preparation has grown remarkably. Nowadays this step of the analytical protocol is not secondary to the chromatographic separation, but it is equally important. Often a careful choice and optimization of the sample preparation is not just desirable but absolutely necessary to achieve an adequate performance. Several clean-up and enrichment methods have been developed to help meet the stricter selectivity and sensitivity requirements of the analytical procedure. Comprehensive two-dimensional gas chromatography (GC×GC) was introduced about two decades ago to further enhance the already high resolving power of GC.

GC×GC is an extremely powerful separation method, its main merits being the unmatched peak capacity arising from employing two independent separation mechanisms at once and the significantly enhanced sensitivity. After a very rapid initial development, limited efforts have been devoted to truly maximizing the performance of the GC×GC set-ups and column combinations. The standard column sets offer an excellent performance, but a further gain is possible by slight modifications of the formats of the columns used in the two dimensions.

Chapter one describes the interactions between sample preparation, separation and detection. It discusses how improvements in one of the steps of the analytical protocol reduce the requirements on the other two. Maximum separation power and sensitivity require a balanced optimization of the three steps, i.e. optimization of each of the three steps in the protocol bearing in mind the requirements, possibilities and limitations of the other steps. The chapter also describes the role of GC and GC×GC when a high selectivity is required. The rather limited attention recently paid to technical refinement in the GC×GC area is discussed. Emphasis also put on the importance of sample preparation. Ideally this

step of the protocol should be used to remove as many of the "uninteresting" compounds as possible. This can be done by exploiting differences in physicochemical properties of the compounds of interest and interfering species. The merits and limitations of the most common trends followed to improve classical liquid-liquid extraction (LLE) are described. Miniaturized devices are particularly attractive in terms of cost, solvent use and ease of on-line interfacing to the separation system.

In *Chapter two* the development of a continuous LLE system with a chip-based extraction unit and segmented flow for the extraction of aqueous samples prior to GC analysis is presented. The use of a micro-machined chip allows to reduce the manual labor and the solvent consumption, while simultaneously providing an excellent repeatability and precise process control. By limiting the miniaturization of the extractor the limitations typical of heavily miniaturized chips are avoided and a simple and robust set-up is obtained. Quantitative extraction yields are obtained for a wide range of hydrophobicities. A wide range of flow rates and flow ratios can be used with good results. The feasibility of the methodology was proven for the detection of amphetamine in urine and for the analysis of chlorinated pesticides and volatile aromatic compounds in water samples.

Chapter three shows the use of hydrophobic polymer monoliths (BMA-EDMA and PS-DVB) as "selective solvent gates" for use in phase separators to achieve continuous separation in segmented flow. The wettability and the pore properties are tuned by changing the polymerization conditions to create a system in which apolar organic solvents can enter the monolith bed, while water is repelled. The prototype of the phase separator is simple and mechanically strong and it yields good results in terms of bleeding and inertness. The device has been coupled to the microextractor described in *Chapter two*. Efficient separation was performed for different organic solvents at a wide range of flow rates/ratios.

In *Chapter four* DVB-based macroporous polymer monoliths are shown to be an interesting second dimension (^{2}D) column format in GC×GC to solve the flow mismatch typical for standard GC×GC column sets. The polymerization mixture, time and temperature are tuned to optimize the columns. Monoliths prepared with long polymerization times show high selectivity, but a low efficiency and a high flow resistance. Short polymerization times and higher DVB contents provide more

open structures with higher plate numbers and faster plate generation rates. Short monolithic columns do not fulfill the ^{2}D plate number requirements, but they show great potential for fast GC thanks to their high retention and selectivity. Peak capacities of up to 12 peaks in 4 seconds are obtained. Multidimensional separations are achieved with the GC×GC set-up with monolithic ^{2}D. Since the structure and the diameter of the monolithic ^{2}D column can be tuned independently, it is possible to tune the flow characteristics which allows simultaneous optimum operation of both dimensions.

Chapter five shows that multi-capillary columns (MCCs) are an efficient ^{2}D column format to solve the flow mismatch encountered in GC×GC. By splitting the flow between several ^{2}D columns the linear velocities in the two dimensions are better balanced and simultaneous optimum operation is possible. Even the smallest inter-column variability has a detrimental effect on the performance of the MCC. Capillaries manufactured to provide high consistency must be used. GC×multi-GC set-ups with multiple ^{2}D columns made of two or three parallel capillary columns are successfully installed. Modulation is performed on the multi-^{2}D to avoid any artifacts caused by the flow splitters. Experimental results confirm that it is possible to fully exploit both dimensions. The two-dimensional chromatograms obtained for a petrol-derived samples and a perfume sample show the suitability of the method in real-life. The hardware is still rather complex, but this approach is of value when a maximum resolving power is required.

Chapter six presents the use of a restrictor at the end of the column set to reduce the linear velocity in the ^{2}D and diminish the GC×GC flow mismatch. At elevated ^{2}D outlet pressures the optima of the two columns are closer together and they can be better exploited while the modulation criterion remains satisfied. Model experiments show that the van Deemter curves so obtained for the ^{2}D are more flat at high velocities than those in standard GC×GC, resulting in a slower loss in efficiency at increasing inlet pressures. The practical gain in terms of resolving power is illustrated by chromatograms obtained for petrol-derived samples. The GC×GC separations achieved are more efficient than those obtained under open outlet conditions. However, the very long analysis times generated make this approach inconvenient in practice.