Trends in Analytical Chemistry, Vol. 27, No. 9, 2008

# Recent developments in automatic solid-phase extraction with renewable surfaces exploiting flow-based approaches

Manuel Miró, Supaporn Kradtap Hartwell, Jaroon Jakmunee, Kate Grudpan, Elo Harald Hansen

**Solid-phase extraction (SPE) is the most versatile sample-processing method for removal of interfering species and/or analyte enrichment. Although significant advances have been made over the past two decades in automating the entire analytical protocol involving SPE via flow-injection approaches, on-line SPE assays performed in permanent mode lack sufficient reliability as a consequence of progressively tighter packing of the bead reactor, contamination of the solid surfaces and potential leakage of functional moieties.**

**This article overviews the current state-of-the-art of an appealing tool for overcoming the above shortcomings, so-called bead-injection (BI) analysis, based on automated renewal of the sorbent material per assay exploiting the various generations of flow-injection analysis. It addresses novel instrumental developments for implementing BI and a number of alternatives for on-line chemical-derivatization reactions, and it pinpoints the most common instrumental detection techniques utilized. We present and discuss in detail relevant environmental and bioanalytical applications reported in the past few years.**

*Keywords:* Bead injection; Bioanalysis; Bioassay; Chemical-derivatization reaction; Detection; Environmental analysis; Flow-injection analysis; Preconcentration; Sample processing; Solid-phase extraction

**Manuel Miró***
Department of Chemistry, Faculty of Sciences, University of the Balearic Islands, Carretera de Valldemossa, km. 7.5, E-07122-Palma de Mallorca, Illes Balears, Spain

**Supaporn Kradtap Hartwell, Jaroon Jakmunee, Kate Grudpan,**
Department of Chemistry and Center of Excellence for Innovation in Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

**Elo Harald Hansen**
Department of Chemistry, Technical University of Denmark, Kemitorvet, Building 207, DK-2800 Kgs. Lyngby, Denmark

## 1. Introduction

The complexity of the matrices of samples in environmental, biological, industrial and biotechnological fields along with the low concentration levels of target species that might be encountered pose severe dilemmas for their direct analysis, even when exploiting modern analytical instrumentation. This is a result of the dependence of the analytical read-outs upon concomitant matrix components, and the fact that the concentration of analytes is often below the dynamic linear range of the detection device. Hence, there is a need, prior to the quantification step, for the development of simple, robust and reliable sample-pretreatment procedures, which are aimed at removing interfering matrix constituents and at the same time improving analyte detectability by preconcentration. When performed in a manual fashion, these preliminary operations are labor intensive and time consuming, difficult to control systematically, and a source of major bias and accidental errors (e.g., sample contamination) that might have a decisive impact on the accuracy and the precision of the analytical results.

The advent of the various generations of flow injection (FI) (i.e. FI, sequential injection (SI), lab-on-valve (LOV)) and

---

*Corresponding author. Tel.: +34 971 172 746; Fax: +34 971173426;
E-mail: manuel.miro@uib.es

0165-9936/$ - see front matter © 2008 Elsevier Ltd. All rights reserved. doi:10.1016/j.trac.2008.07.003

hybrid techniques for on-line or in-line sample processing has opened new perspectives as regards automation and miniaturization of sample handling with the extra advantage of saving sample and reagent consumption and reducing waste generation [1,2].

This review illustrates the current state-of-the-art of the so-called bead-injection (BI) technique, which performs the entire solid-phase extraction (SPE) procedure in a renewable fashion in flowing systems. In contrast with earlier reviews dealing with BI [3–6], this article critically discusses the overall platforms described in the literature for BI-based SPE analysis and illustrates alternative approaches for uptake and detection of target species. We also describe in detail pros and cons of BI assays, compared with conventional particle-packed microcolumns, for flow-based SPE, via selection of representative examples in the environmental and bioanalytical fields, as reported within the past decade.

## 2. On-line solid-phase extraction

Sorptive extraction is the predominant sample-processing method to be automated by resorting to flow systems as a consequence of its straightforward operation, high separation and preconcentration capabilities and minimum consumption of organic solvents. Most often, it is employed by using packed-bed or disk-phase-based microcolumns, which are filled with appropriate sorptive materials and placed within the flow network prior to the detection device.

The ultimate goal is to improve the sensitivity of the analytical procedure and/or overcome the inherently low tolerance of the detection system to sample constituents by preconcentrating the analyte or removing interfering components from harsh milieus (e.g., high-salt or protein-content matrices) with no need for sample dilution. Several solid-phase reactors with different designs, mainly uniformly-bored or conical microcolumns, have been successfully assembled in flow-based set-ups. The temporary retention of low-level concentrations of individual metal ions, nutrients and charged (bio)molecules by electrostatic interactions onto ion-exchange microcolumns or chelating reactors has been a common practice in flow-through SPE methods [7]. Derivatized non-polar metal chelates (e.g., iminodiacetates, dithiocarbamates, dithiophosphates or quinolinates) or hydrophobic species (e.g., organic pollutants, dyes and drugs) have been preconcentrated on reversed-phase materials (e.g., octadecyl-chemically modified silica gel, polytetrafluoroethylene (PTFE) beads or turnings, or multimodal polymeric sorbents) by partitioning, hydrophobic, or π-π interactions [1,7]. The target compounds are either directly retained on the reactive surfaces after appropriate sorbent conditioning or in-line derivatized into a suitable chemical form. This extraction mode circumvents interfering effects from alkaline and alkaline-earth elements when determining hazardous trace metals via intelligent selection of the chelating reagent [1].

As detailed above, flow-through SPE procedures have been implemented using permanent packed-column reactors. However, these sorptive columns are prone to problems in long-term operation due to the progressively tighter packing or clogging of the column material resulting in increase of back pressure, which might be alleviated to some extent by back-flushing elution protocols. Further drawbacks of on-line SPE with reusable surfaces are analyte carry-over effects, shrinking or swelling of the sorbent bed, malfunctions of the active entities including loss of functional moieties (the last of these being a common problem for reagent-impregnated bead materials) and, finally, surface deactivation due to irreversible sorption of interfering species. All these problems can be eliminated by exploiting the concept of renewable surfaces, or, as it has been termed, BI, i.e. where the solid-phase material, if called for, can be renewed for each analytical cycle.

## 3. The concept of bead injection

The BI approach originally adapted to optical sensing in SI analyzers was introduced as a powerful tool for the automation of immunoassays using diffuse reflectometric detection [4]. The miniaturized BI chemosensors use minute amounts of beads carrying the derivatization reagent or functional moieties, whereby the analyte becomes preconcentrated and can be monitored via optical fibers in custom-built flow-through cells that capture the active sensing surfaces while allowing the perfused liquid to flow freely [4]. After each analytical run, the sorbent particles are disposed by flow reversal and the sensor surface is renewed by injecting a new plug of a fresh bead suspension. This concept of optical sensing at solid surfaces, also termed solid-phase optosensing or BI spectroscopy, constitutes an attractive alternative to on-line SPE procedures with eluate detection for preventing the partial loss of the preconcentration capabilities gained during the sorption step as a result of dilution of the eluate plug when delivered to the detector [8]. Moreover, BI fosters real-time monitoring of the sorption process and thus detection relying on initial rate measurements can be readily accomplished. A further advantage of BI derived from its characteristic renewability is its inherent flexibility in accommodating reagent-based SPE assays with no stringent demands as to the full reversibility of the sorption or elution procedure. This is the case in uptake of Fe(II)-1,10-phenanthroline onto chelating beads because eluents, such as nitric acid or EDTA, are inefficient for quantitatively stripping out the chelate from the beads [9].