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Review

Electrical field-induced extraction and separation techniques: Promising trends in analytical chemistry – A review

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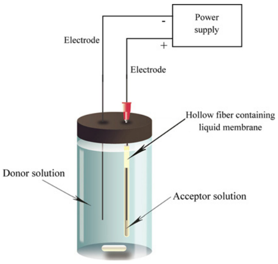
HIGHLIGHTS

- Sample preparation is an important issue in analytical chemistry.
- Application of electrical potential reduces time and enhances selectivity in sample preparation.
- Review provides an overview of principles and applications of electrical fields in sample preparation.
- Advantages, disadvantages and point to the corresponding limitations of these techniques are discussed.
- Review is interested for readers that are appreciated to field of electrochemically modulated extractions.

GRAPHICAL ABSTRACT



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ABSTRACT

Sample preparation is an important issue in analytical chemistry, and is often a bottleneck in chemical analysis. So, the major incentive for the recent research has been to attain faster, simpler, less expensive, and more environmentally friendly sample preparation methods. The use of auxiliary energies, such as heat, ultrasound, and microwave, is one of the strategies that have been employed in sample preparation to reach the above purposes. Application of electrical driving force is the current state-of-the-art, which presents new possibilities for simplifying and shortening the sample preparation process as well as enhancing its selectivity. The electrical driving force has scarcely been utilized in comparison with other auxiliary energies. In this review, the different roles of electrical driving force (as a powerful auxiliary energy) in various extraction techniques, including liquid-, solid-, and membrane-based methods, have been taken into consideration. Also, the references have been made available, relevant to the developments in separation techniques and Lab-on-a-Chip (LOC) systems. All aspects of electrical driving force in extraction and separation methods are too specific to be treated in this contribution. However, the main

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Abbreviations: CEC, capillary electrochromatography; CE, capillary electrophoresis; CPs, chlorophenols; DEHP, di-(2-ethylhexyl) phosphate; DPV, differential pulse voltammetry; ELMME, electrochemical liquid membrane microextraction; EMLC, electrochemically modulated liquid chromatography; ED, electrodialysis; EF, electrofiltration; EME, electrokinetic membrane extraction; EMIS, electromembrane ion source; EM-SPME, electromembrane surrounded solid phase microextraction; EMF, electro-microfiltration; EO, electro-osmosis; FID, flame ionization detector; HIS, histidine; HF-LPME, hollow fiber-based liquid-phase microextraction; ITIES, interface between two immiscible electrolyte solutions; IC, ion chromatography; LOC, Lab-on-a-Chip; LLE, liquid–liquid extraction; LDS-USAEME, low-density solvent based ultrasound-assisted emulsification microextraction; LPME, liquid-phase microextraction; μTAS, Micro Total Analysis Systems; MEMS, microelectromechanical systems; ME, microchip electrophoresis; MEC, microchip electrochromatography; MWCO, molecular weight cut-off; NPPE, 2-nitrophenyl pentyl ether; NPOE, 2-nitrophenyl octyl ether; N.E., non-electrically; PHE, phenylalanine; PEME, pulsed electromembrane extraction; SPE, solid-phase extraction; SLM, supported liquid membrane; TDP, tridecyl phosphate; TEHP, tris(2-ethylhexyl) phosphate; TRY, tryptophan; VALC, voltage-assisted liquid chromatography.

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aim of this review is to provide a brief knowledge about the different fields of analytical chemistry, with an emphasis on the latest efforts put into the electrically assisted membrane-based sample preparation systems. The advantages and disadvantages of these approaches as well as the new achievements in these areas have been discussed, which might be helpful for further progress in the future.

Contents

Yadollah Yamini was born in 1968 in Dizajkhalil (Shabestar, Iran), and obtained his B.Sc. from Mazandaran University (Babolsar, Iran, 1990), his M.Sc. from Tarbiat Modares University (Tehran, Iran, 1992) under the supervision of Dr. M. Ashraf Khorassani, and his Ph.D. from Tarbiat Modares University (1996) under the supervision of Prof. M. Shamsipur. He has been a faculty member of Tarbiat Modares University since 1997, and was promoted to Professor in 2006. Professor Yamini's research involves the development of sample preparation methods based on the elimination or reduction of organic solvents, such as solid-phase extraction, supercritical fluid extraction, solvent microextration, solid-phase microextraction, electromembrane microextraction, and supramolecular solvent microextraction. He is the referee of manuscripts for more than 45 different ISI journals. He has published more than 245 scientific articles in the ISI journals. Also, he wrote a chapter, entitled "Environmental applications of cloud-point extraction", from Comprehensive Sampling and Sample Preparation, which was published by Elsevier in 2012.

Maryam Rezazadeh is currently a Ph.D. student in analytical chemistry at the Department of Chemistry, Tarbiat Modares University (TMU), under the direction of Prof. Yadollah Yamini. She received her bachelor's degree (B.Sc.) in pure chemistry at the National University of Iran (Shahid Beheshti University, SBU, Tehran, Iran) in 2009. She got her master's degree (M.Sc.) under the direction of Prof. Yadollah Yamini at TMU in 2011. Her field of interest is the development of new microextraction technologies, with an emphasis on electrically induced sample preparation methods and separation techniques.

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1. Introduction

Analytes of environmental or biological origin, which usually occur in complex matrices, are able to disturb the separation and data analysis stages. With regard to these concerns, a series of steps are required to remove the interfering substances, preconcentrate the analytes, and increase the sensitivity. As a consequence, the development of new analyte extraction methods and technologies has received major attention from the analytical research communities around the world.

These innovative techniques are derived from traditional sample treatment methods, namely liquid–liquid extraction (LLE) and solid-phase extraction (SPE). The benefits, which motivated the research and development of sample preparation techniques, are analytical improvement, scaling down the sample sizes, overcoming the sample matrix effects, automation, speed of response, and lower costs.

In recent years, a number of general reviews on sample preparation have been documented, covering different aspects of various methods [1–8]. Electric field-induced extraction is a topic that is less investigated.

Fig. 1A–D illustrates the number of publications related to some of the main electrically assisted extraction techniques with the keywords of "electromembrane extraction", "electrochemically solid-phase extraction", "electroextraction", and "electrochemically modulated liquid–liquid extraction" that are limited to the titles and keywords of articles incorporated in the Scopus database [9]. Fig. 1E shows the total number of publications in each year, obtained by summation of publications associated with the mentioned techniques in different years. Although this graph is not an exact criterion for all publications concerning the electrically assisted extraction methods, it can provide useful insight into these techniques. Regarding Fig. 1E and the number of citations of electrically assisted sample preparation techniques accessible at online databases, it can be concluded that these methods are gradually becoming quite commonplace in analytical chemistry.

The starting point for electrically induced extraction techniques dates back to the beginning of the 19th century, when the initial studies on the migration capability of particles in solutions under