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Review Article

Application of hollow fiber liquid phase microextraction and dispersive liquid–liquid microextraction techniques in analytical toxicology

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ABSTRACT

The recent developments in hollow fiber liquid phase microextraction and dispersive liquid–liquid microextraction are reviewed. Applications of these newly emerging developments in extraction and preconcentration of a vast category of compounds including heavy metals, pesticides, pharmaceuticals and abused drugs in complex matrices (environmental and biological matrices) are reviewed and discussed. The new developments in these techniques including the use of solvents lighter than water, ionic liquids and supramolecular solvents are also considered. Applications of these new solvents reduce the use of toxic solvents and eliminate the centrifugation step, which reduces the extraction time.

1. Introduction

There is no doubt that reliability, precision and accuracy of the results of any analytical procedure are strongly dependent on the sample preparation method, especially when trace and ultratrace levels of the analytes in complex matrices (biological and environmental) should be analyzed. Indeed, sample preparation is often thought to be the most critical step in the whole analytical procedure because its steps account for one-third of the errors generated by the analytical method [1]. The traditional sample preparation technique is liquid–liquid extraction (LLE). Despite extensive use of this method over the years it has important disadvantages. The LLE method is tedious, time consuming and uses large amount of toxic solvents [2]. In order to overcome these drawbacks, a great number of efforts have been made to develop new extraction techniques. The final goal of these efforts is to develop simple,

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rapid and inexpensive techniques that consume the minimum volume of toxic solvents and have the ability of automation. The efforts of different researchers in this area have resulted in the invention and development of new extraction techniques known as liquid-phase microextraction (LPME). The LPME is a solvent-minimized sample pretreatment procedure of LLE, in which only several microliters of solvent is required to concentrate analytes from various samples rather than hundreds of milliliters needed in traditional LLE. The other advantages of LPME are simplicity of operation, rapidity, low cost, high recovery and high enrichment factor [3]. The LPME can be divided into three main modes [4]: (1) single-drop microextraction; (2) hollow-fiber liquid phase microextraction (HFLPME); and (3) dispersive liquid–liquid microextraction (DLLME). Among these modes of LPME, HFLPME and DLLME have received much attention because of their benefits.

In this review, the recent developments including the use of ionic liquids and supramolecular solvents in HFLPME and DLLME and applications of HFLPME and DLLME in the extraction and preconcentration of different analytes from complex matrices (environmental and biological) are discussed.

2. HFLPE

HFLPME is a mode of LPME that uses a porous polypropylene hollow fiber for immobilization of organic solvent in the pores of hollow fibers. This technique was introduced by Pedersen-Bjergaard and Rasmussen [5]. The main components of this technique are: (1) donor phase that usually is an aqueous sample containing the analytes of interest; (2) porous polypropylene hollow fiber for immobilization of organic solvent in its pores; (3) organic solvent that is immobilized in the pores of the hollow fiber; and (4) acceptor phase that usually is an organic, acidic or basic solution that fills the inside of the hollow fiber lumen.

From a practical point of view, a short piece of a porous hollow fiber is dipped in the organic solvent in order to immobilize solvent in its pores. Thus, a thin layer of organic solvent is formed within the wall of the hollow fiber. In the next step, the lumen of the hollow fiber is filled with an appropriate acceptor solution and then the hollow fiber is placed into the sample vial containing the sample donor phase. Extraction takes place from the donor phase into the organic layer on the walls of the hollow fiber and then into the acceptor phase inside the lumen of the hollow fiber.

2.1. *Different modes of HFLPME*

According to the type of acceptor phase and solution agitation, HFLPME is classified into different modes. (1) Two phase HFLPME: in this mode the acceptor solution is the same organic solvent immobilized in the pores of the hollow fiber. This mode is usually used for the extraction of analytes with a solubility in an organic solvent immiscible with water. (2) Three phase HFLPME: in this mode, the acceptor phase is an acidic or alkaline aqueous solution. The analytes are extracted from an aqueous sample, through the thin film of organic solvent and then into an aqueous acceptor solution. This extraction mode is limited to basic or acidic analytes with ionizable functions. In this mode of HFLPME, the pH adjustment plays a central role. For acidic analytes, the pH of the donor phase should be adjusted into the acidic region to suppress the ionization of analytes and keep them in their neutral form to be dissolved more effectively in organic solvent. The acceptor phase in this case should be an alkaline solution to guarantee the ionization of analytes and their extraction into the acceptor phase [6]. The situation for basic analytes is the reverse. The donor phase (sample matrix) is an alkaline and the acceptor phase is an acidic solution. (3) Static mode: in this mode of HFLPME, extraction speed is enhanced by stirring the sample solution usually using a magnetic stirrer. (4) Dynamic mode: in this mode, using the syringe plunger, small volumes of the aqueous sample are repeatedly pulled in and out of the hollow fiber [7]. Dynamic HFLPME improves extraction speed, as compared with static systems but operation in the dynamic mode complicates instrumentation and adds experimental parameters that have to be optimized and controlled [4]. Different steps of HFLPME are shown in Fig. 1.

2.2. *Parameters affecting the extraction efficiency of HFLPME*

Different parameters affect the efficiency of HFLPME, including type of hollow fiber materials, type of organic solvent, extraction time, pH of donor and acceptor phases, temperature and salt addition.

2.2.1. *Selection of hollow fiber materials*

To achieve better results of HFLPME, the hollow fiber should be slightly hydrophobic so that the micropores in the hollow fiber can be impregnated with the organic extraction solvent. Polyethersulfone and polyvinylidene fluoride are usually used for extraction [8]. From the view of atom orbitals sulfur atom has d orbitals that can accommodate the valent electrons to form complex polar resonance structures. On the contrary, the fluorine atom in the structure of polyvinylidene fluoride has stronger nucleophilicity [8].

2.2.2. *Type of organic solvent*

The type of extraction solvent is an important factor that has a great effect on the extraction efficiency. Ideally, organic solvent in HFLPME should be nonvolatile, immiscible with water, strongly immobilized within the pores of the hollow fiber, be able to provide high solubility for the target analytes, and should be compatible with the instrumental analysis system. Solvents such toluene, chloroform, 1-octanol and *n*-hexyl ether are usually used as organic solvents in HFLPME. Recently application of ionic liquids [9–12] and supramolecular solvents [13,14] as an efficient solvent for extraction in HHLPME has increased.

2.2.3. *Effect of the pH of donor and acceptor phases*

The pH of the donor and acceptor phases plays a major role in extraction efficiency, especially when the target analytes have ionizable functional groups. The pH of donor phase should be adjusted to a level that guarantees the neutrality of analytes and consequently reduces their solubility in the sample