Chemical Engineering Journal 226 (2013) 171–180

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Molecularly imprinted polymers for selective separation of acetaminophen and aspirin by using supercritical fluid technology

Soon-Do Yoon, Hun-Soo Byun *

Department of Chemical and Biomolecular Engineering, Chonnam National University, Yeosu, Jeonnam 550-749, South Korea

HIGHLIGHTS

- AAP or AS imprinted polymers were prepared by supercritical polymerization in CO_2.
- Adsorption properties were evaluated with the adsorption isotherm and Scatchard analysis.
- The recognition abilities were superior to that of the target molecules and others.
- Selectivity of MIPs used via supercritical polymerization was better than other methods.

ARTICLE INFO

Article history:
Received 4 November 2012
Received in revised form 8 April 2013
Accepted 12 April 2013
Available online 21 April 2013

Keywords:
Supercritical fluid technology
Molecularly imprinted polymers
Adsorption properties
Acetaminophen
Aspirin

ABSTRACT

In this study, we synthesize molecularly imprinted polymers (MIPs) by using supercritical fluid technology in carbon dioxide (CO_2). To prepare MIPs, methyl methacrylate (MMA) is used as a third monomer, methacrylic acid (MAA) or 4-vinylpyridine (4-VP) as functional monomers, acetaminophen (AAP) and aspirin (AS) as templates, and ethylene glycol dimethacrylate (EGDMA) as a crosslinker. To evaluate the binding characteristics of MIPs for AAP and AS, equilibrium binding experiments are conducted. The results indicate that the adsorption equilibrium time is about 120 min, and the binding amount increases with the concentration of templates. The adsorption ability of the MIPs is also investigated by performing an HPLC analysis, measuring the adsorbed amounts for templates and their structural analogue, the selectivity factor (α), and the imprinting-induced promotion of binding (IPB). The results of the evaluation analysis indicate that the prepared MIPs have high separation abilities and selectivity. In addition, the molecular recognition properties according to the kind of functional monomers (MAA and 4-VP) and polymerization methods indicate that the use of 4-VP as a functional monomer is more efficient for binding yield and affinity, and the MIPs prepared by using supercritical fluid assisted polymerization are more efficient way to selectively separate and detect templates than bulk and emulsion polymerization process.

1. Introduction

Supercritical fluids (SCFs) have specific properties which can be reinforced by many types of chemical process operations. An additional advantage of SCFs is that they can replace many environmentally harmful solvents currently used in industry. Especially, SCFs are an attractive alternative to organic solvents to be used as additives in polymer processing or preparation. That is, supercritical carbon dioxide ($scCO_2$) is by far the most widely used SCF because its zero ozone-depletion potential makes it relatively cheap, nontoxic, nonflammable, eco-friendly, and acceptable. It has low critical constants of $T_c = 31$ °C and $P_c = 74$ bar [1,2]. Because CO_2 is a gas under ambient conditions, it is very easily removed from the polymeric product, avoiding the costly processes of drying or solvent removal, which is very important in processing and preparing of polymer-based materials.

As a polymerization medium, $scCO_2$ provides some advantages over the conventional solvents. High density of $scCO_2$ enable easy adaptation to reactions of polymerization, thus composed polymer chains precipitate from the solution after reaching a specific molecular weight. Moreover, $scCO_2$ can be used to extract unreacted monomers, initiators, catalysts, and some stabilizers from polymer products to achieve highly pure materials.

Molecular imprinting is an applied technique to prepare a stable synthetic polymer matrix called molecularly imprinted polymers (MIPs) that contain highly specific sites having an affinity for a target or template molecule. The general preparation procedure of MIPs is illustrated in Fig. 1. MIPs are used as a selective support in liquid chromatography [3,4], capillary electrophoresis [5,6], and solid-phase extraction [7–9], and it is also used as biosensors

* Corresponding author. Tel.: +82 61 659 7296; fax: +82 61 653 3659.
E-mail address: hsbyun@chonnam.ac.kr (H.-S. Byun).

1385-8947/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cej.2013.04.052

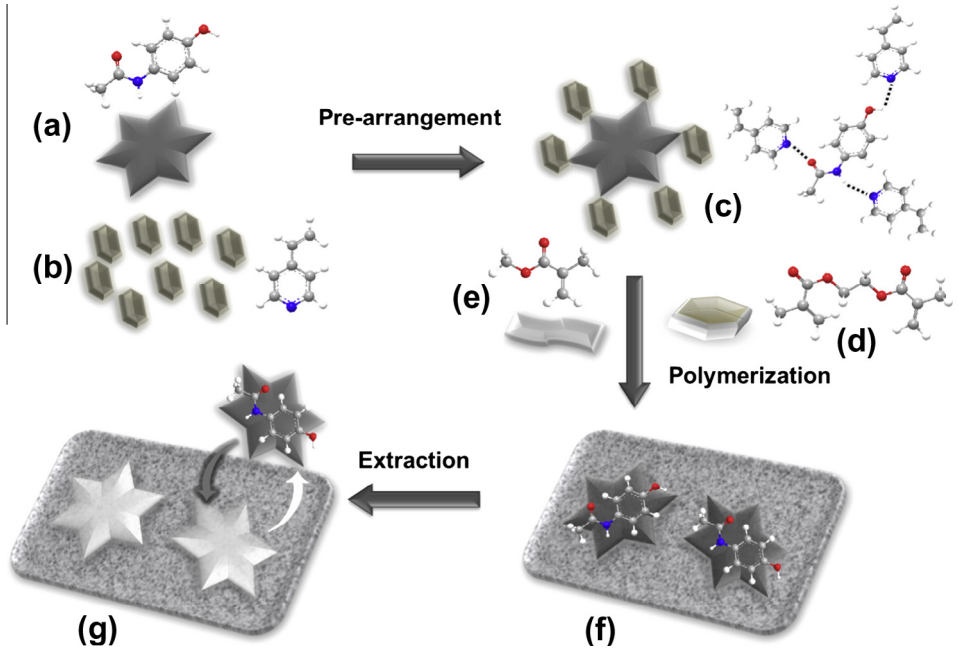

Fig. 1. Schematic representation of molecularly imprinted polymers. (a) Template, (b) functional monomer, (c) print molecule, (d) crosslinker, (e) third vinyl monomer, (f) bulk polymer, and (g) template-imprinted polymer.

[10,11] or artificial antibodies [12] due to physical–chemical stability and ability of high recognition.

MIPs can be synthesized by the covalent [13] or noncovalent [14,15] method, which is now widely used in bulk polymerization [16], in situ polymerization [17], suspension polymerization [18], precipitation polymerization [19], and multi-step swelling polymerization [20]. The most common MIPs are prepared in a bulk form by using bulk polymerization. They are crushed and subsequently ground to gain appropriately sized particles. This method has the advantages of ease for preparing MIPs. However, heterogeneity of polymer matrix can occur during the polymerization process. In addition, the crushing and grinding process causes large loss and destruction of cavity in the template shape of the prepared MIPs. In order to complement the weakness of bulk polymerization, various methods have been attempted to prepare MIP particles such as suspension, emulsion, dispersion, solution, and precipitation polymerization. The MIP particles are easily gained by using these methods. Particle sizes of MIPs are also controlled for applications in various fields. However, these methods are flawed by the difficulty in selecting dispersion agent and mediums because the relation of combinations or solubility between components should be considered. Moreover, the process of polymerization for the formation of MIPs matrix is complex because the multi-step process required. Furthermore, in the case of dispersion, solution, and precipitation polymerization, MIP particles are prepared by using organic solvents. Use of organic solvents has an adverse effect not only on the environment, but also on the selective separation of template molecules. In order to overcome the drawbacks of these polymerization methods and to minimize the consumption of organic solvents, many studies have been carried out using supercritical fluid assisted polymerization in $scCO_2$ as the reaction medium to prepare MIPs in a heterogeneous reaction system [1,21]. The preparation of MIPs using supercritical fluid assisted polymerization provides the following advantages: High purity products are easily obtained. They are synthesized using CO_2 as an eco-friendly solvent. The preparation process of MIPs is relatively simple. In addition, the MIPs synthesized using supercritical fluid assisted polymerization are obtained as free-flowing powders with controlled morphology and porosity [22].

Acetaminophen (AAP) is commonly used for the relief of headaches and other minor aches and pains, and it is a major ingredient in numerous cold and flu remedies. However, its overdoses can cause potentially fatal liver damage [23]. The first drug in the non-steroidal anti-inflammatory (NSAID) class, Aspirin (AS) has been used as an anti-inflammatory agent or an antipyretic analgesic. More recently, AS is being evaluated for the prevention of two leading causes of death, i.e., cardiovascular disease and cancer [24,25]. Active pharmaceuticals such as antipyretic analgesics or antibiotics have become a major concern in the aquatic environment pollution [26]. In addition, it is necessary to detect these compounds for the prevention of their abuse. The environmental pollution could be attributed to excretion of pharmaceuticals and their metabolites in urine and feces, and inappropriate disposal of unused pharmaceuticals [27]. Detection of these pharmaceutical products in the blood of human or in the natural environment would not only make it possible to predict a particular disease or optimize the dosage but also protect the environment.

In this study, AAP and AS imprinted polymers were synthesized by using supercritical fluid assisted polymerization in $scCO_2$. The binding characteristics of prepared MIPs are investigated by adsorption kinetics, adsorption isotherms, and Scatchard plot analysis. The selective separation abilities of MIPs were analyzed by high performance liquid chromatography (HPLC) analysis, the adsorption of materials with structures similar to target molecules (AAP and AS), the selectivity factor (α), and the imprinting-induced promotion of binding (IPB). The effects of various polymerization methods and different functional monomers were also investigated.

2. Experimental

2.1. Materials

We purchased the following from Aldrich Chemical Company, Inc. (Milwaukee, WI, USA): acetaminophen (AAP), aspirin (AS), benzoic acid (BA), salicylic acid (SA), p-toluic acid (p-TA), 1-naphthoic acid (1NA), methyl methacrylate (MMA), ethylene glycol