Journal of Chromatography A, 1465 (2016) 143–154

Contents lists available at ScienceDirect

Journal of Chromatography A

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

Highly efficient recovery of xylobiose from xylooligosaccharides using a simulated moving bed method

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ARTICLE INFO

Article history:
Received 5 July 2016
Received in revised form 25 August 2016
Accepted 27 August 2016
Available online 30 August 2016

Keywords:
Simulated moving bed
Xylobiose
Xylooligosaccharides
Prebiotics
High purity

ABSTRACT

Xylobiose (X2), which is currently available from xylooligosaccharides (XOS), has been reported to have outstanding prebiotic function and to be highly suitable for application in food industries. This has sparked an interest in the economical production of X2 of high purity (> 99%) in food and prebiotic industries. To address such issue, we developed a highly-efficient chromatographic method for the recovery of X2 from XOS with high purity and high recovery. As a first step for this work, an eligible adsorbent for a large-scale separation between X2 and other XOS components was selected. For the selected adsorbent, a single-column experiment was carried out to determine the intrinsic parameters of all the XOS components, which were then used in the optimal design of the continuous X2-recovery process based on a simulated moving bed (SMB) chromatographic method. Finally, the performance of the designed X2-recovery SMB process was verified by the relevant SMB experiments, which confirmed that the developed process in this study could recover X2 from XOS with the purity of 99.5% and the recovery of 92.3% on a continuous-separation mode. The results of this study will be useful in enabling the economical production of high-purity X2 on a large scale.

1. Introduction

Xylooligosaccharides (XOS) have prebiotic functions for human intestinal bifidobacteria, which is recognized to be beneficial to humans in terms of both health and nutrition [1–6]. XOS consist of oligosaccharides containing two to seven xylose monomers, which differ in molecular weight and degree of polymerization [3,4]. Among the XOS components, the dimer xylobiose (X2) was reported to have the highest prebiotic activity in bifidobacterium proliferation and to be the most suitable for application in food industries [1,7–10]. This has ignited an interest in developing a highly efficient separation process for recovery of xylobiose (X2) from XOS on an industrially competitive mode, in which both the continuous loading of XOS mixture and the continuous collection of X2 product can be implemented simultaneously while maintaining high X2 purity (> 99%).

In regard to the aforementioned issue, it is quite worth considering the adoption of the process structure and the operation principle of a simulated moving bed (SMB) technology, which has proved to be highly suitable for separating bioproducts in a continuous mode in the literature [11–14] and is thus expected herein to facilitate the development of the X2-recovery process under consideration.

The core of the SMB technology is to use multiple adsorbent columns connected in series and multiple ports switched periodically (Fig. 1), under which a model simulation is conducted beforehand to predict the separated and the overlapped regions between the less retained (slow-migrating) and the more retained (fast-migrating) solutes [15–17]. If such multiple adsorbent columns, multiple ports (inlet and outlet ports), and the model prediction can be exploited properly in an integrated way, it is possible to operate a separation process based on the SMB technology (i.e., SMB process) such that a feed mixture can always be made to be loaded into the overlapping region of two solute bands while a product can always be made to be withdrawn from the separated region [15–18].

If the above-mentioned SMB process is developed for the recovery of X2 from XOS, it will surely improve the economical efficiency of the X2 production process, and will thus be able to boost the competitiveness of related prebiotic industries.

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http://dx.doi.org/10.1016/j.chroma.2016.08.063
0021-9673/

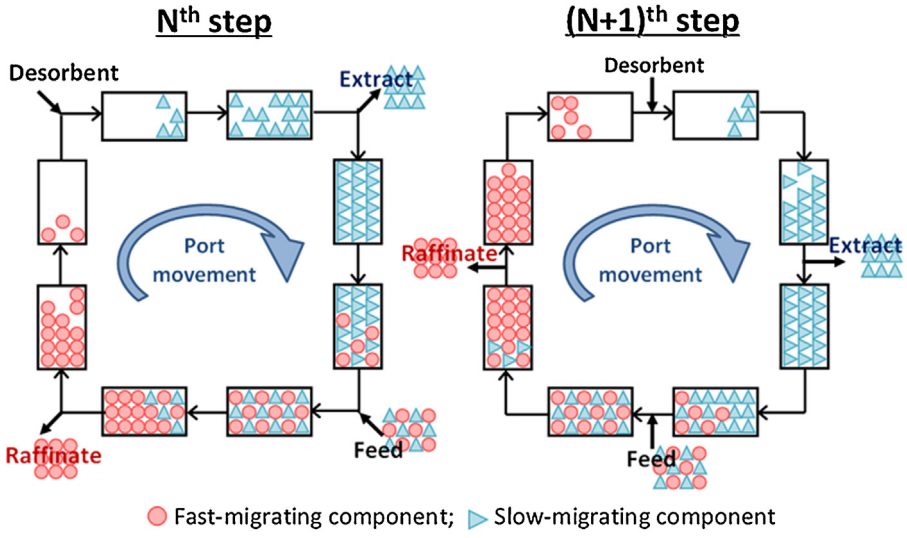

Fig. 1. Illustration of a classical four-zone SMB process for binary separation.

There have been several previous studies on the separation for a mixture containing oligosaccharides. Geisser et al. [19] demonstrated the feasibility of separating lactose from human milk oligosaccharides with an SMB technique based on a size-exclusion gel. Gramblička and Polakovič [20] measured the adsorption equilibrium data for glucose, fructose, sucrose, and fructooligosaccharides on cation exchange resins. Xie et al. [21] developed a five-zone SMB for removal of sulfuric and acetic acids from monosaccharides and disaccharides, which could be fermented to produce bioethanol. Rabelo et al. [22] and Wiśniewski et al. [23] investigated the chromatographic separation parameters of isomaltooligosaccharides and galactooligosaccharides respectively. However, no previous studies have hitherto been carried out about the X2 production from XOS using SMB technology.

The goal of this study is to accomplish the aforementioned work, i.e., to develop an optimal SMB process that can recover X2 of high purity (>99%) from XOS with a sufficiently high recovery. As a first step for this work, a proper adsorbent with sufficient selectivity between X2 and other XOS components was selected among commercially available adsorbents that were qualified for a large-scale and long-term production. For the selected adsorbent, the intrinsic parameters of all the XOS components were estimated through a single-column experiment. The estimated parameters of the XOS components were then utilized in the optimal design of the SMB process under consideration. Finally, it was verified from both computer simulations and the relevant SMB experiments that the developed process in this study could recover X2 from XOS on a continuous-separation mode while maintaining the X2 purity and recovery higher than 99% and 92% respectively.

2. Materials and methods

2.1. Materials

Powder XOS from Shandong Longlive Bio-technology Co. (Yucheng, China), which had undergone an ion-exchange treatment for removal of salt ions during its manufacturing process, was provided gratis by TS Corporation (Incheon, Korea), which is one of the big domestic companies for sugar production. The powder XOS was dissolved in distilled deionized water to prepare XOS solution, which was used as a feed solution to be loaded into the SMB process under consideration. Distilled deionized water (DDW) was obtained from a Milli-Q system by Millipore (Bedford, MA) and used as a desorbent in the SMB experiments performed.

The Dowex-50WX4 resin, which was purchased from the Sigma-Aldrich Co. (St. Louis, MO), was received in hydrogen form. To convert the resin to the sodium form, it was first washed with fived bed volumes of 0.5 M NaCl in up-flow, and then washed with fived bed volumes of DDW in down-flow. After such washing treatments, the resin was equilibrated in DDW. The resin pretreated in such manner was packed into an omnifit chromatographic column, which was purchased from the Bio-Chem Fluidics Co. (Boonton, NJ). The diameter and length of this column are 3.5 cm and 21.7 cm respectively. The bed voidage and particle porosity of the packed column were 0.3 and 0.629 respectively, which were obtained from a series of tracer-molecule pulse tests. The average diameter of the resin particle is 55.5 μm.

2.2. Instrumentation

An ÄKTA™ fast protein liquid chromatography (FPLC) system, which was manufactured by Amersham Biosciences Co. (Piscataway, NJ), was used in a single-column experiment. This system consists of two pumps (Amersham Biosciences P-920), a high-performance monitor (Amersham Biosciences UPC-900), and a fraction collector (Amersham FPLC Frac-900). The two pumps and the fraction collector were controlled by UNICORN 5.1 software, which operated in the Windows environment.

As the experimental unit for the SMB separation of interest, a three-zone SMB process that could accommodate two different patterns of port configurations was assembled in our laboratory on the basis of the guidelines of SMB hardware assemblage in the literature [24]. This unit consisted of four rotary valves, three pumps, and four columns as seen in Fig. 2. The rotary valve used was the Select-Trapping (ST) valve from VICI Valco Instruments (Houston, TX). This valve was connected to each column for implementation of periodic port movement, which occurs at the same time with the valve switching. All the actions associated with such a valve switching were controlled by a computer with Labview 8.0 software from National Instruments (Austin, TX). For control of the flow rates, three pumps were employed in this SMB unit. A single-piston pump (Model QV) purchased from Fluid Metering Inc. (Syosset, NY) was used to control either raffinate or extract flow rate. The outlet flow rate to be controlled between the raffinate and extract flow rates was chosen depending on the way of port arrangement,