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Dynamics of a True Moving Bed separation process: Effect of operating variables on performance indicators using orthogonalization method

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ABSTRACT

The assessment of the performance of cyclic adsorption systems is usually addressed in literature in terms of steady state. To reach further developments in this field, the characterization of the dynamic behavior of the processes becomes necessary. This work focus on the application of a method based on Gram-Schmidt Orthogonalization to analyze the impact of the operating variables in the dynamic response of a TMB unit. Another objective of this work is to characterize the dynamic system behavior and compare it with the orthogonalization method results. The results showed that the recycling flow rate is the operating variable with the greatest impact for the system considered. The step perturbation analysis showed the consistence of the proposed method and that some process variables result in a system inverse response for the recovery performance indicator. The importance of taking in consideration the process dynamics in the unit design, control and optimization is demonstrated.

1. Introduction

In the last two decades, studies of cyclic adsorption systems presented a great advance. Among these systems we can emphasize the True Moving Bed (TMB) and the Simulated Moving Bed (SMB) chromatographic systems. These units are characterized by the capability to promote efficient separations even for systems with reduced selectivity and, to simultaneously conduct some reactions, intensifying the production of target compounds with improved purity. Some works in the literature presented these processes as a route of production, alternative to the traditional one. These works demonstrated the advantages of this technology. The type of systems studied are diverse, as for example enantiomers separation, e.g., Bi-naphthol (Pais et al., 1997; Minceva et al., 2003); Guaifenesine (Francotte and Richert, 1997; Gomes et al., 2010; Grossmann et al., 2010); Flurbiprofen (Ribeiro et al., 2011). Other studies are focused on the optimization (Klatt et al., 2002; Toumi and Engell, 2004; Toumi et al., 2007; Agrawal et al., 2014a, 2014b) or control (Klatt et al., 2002; Abel et al., 2004; Song et al., 2006; Zahn et al., 2011; Suvarov et al., 2012) of these types of process, contributing to the development of further knowledge in the field.

In the majority of the works found in literature the assessment of the performance of cyclic adsorption systems is usually addressed in terms of steady state or cyclic steady state (Pais et al., 2000; Minceva et al., 2003; Kaspereit et al., 2007; Toumi et al., 2007; Agrawal et al., 2014b). This is a valid approach when the focus is the process after reaching its steady or cyclic steady state. When the focus becomes the trajectory that the process takes between states, a further analysis is necessary. This happens in units that can produce different types of products (e.g., products with different specifications). Usually in this kind of processes the product is characterized by its purity or final composition. So, it is essential to know how the process behaves in its transient state. Furthermore, as indicated by Kaspereit et al. (2007), there is a lack of methods for optimal design of SMB units under reduced purity requirements. This means that a novel method is necessary to analyze the system behavior and optimize the unit design when the purity is not constrained. An important step towards this objective is the development of a method capable of making an overall analysis of the dynamic behavior of the system taking in consideration not only the purity, but all desired performance parameters.

This work focuses on the application of a method based on Gram-Schmidt Orthogonalization to analyze the impact of the operating variables in a TMB unit response. The dynamic behavior of the system was characterized and the results were compared with the orthogonalization method results. In this way, it was possible to show the consistence of the orthogonalization method results

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Nomenclature

$\vec{a}$	Generic vector (dimensionless)
c	Fluid phase concentration (mol m^{-3})
D_L	Axial dispersion coefficient (m^2 s^{-1})
EC	Eluent consumption (m^3 kg^{-1})
M	Magnitude (dimensionless)
n	Number of time instant (dimensionless)
Pe	Peclet number (dimensionless)
Pr	Productivity (kg day^{-1} per m^3 of bed)
q	Adsorbed phase concentration (mol m^{-3})
q^*	Adsorbed phase concentration in equilibrium with c (mol m^{-3})
Q	Flow rate (m^3 s^{-1})
R	Residual matrix (dimensionless)
t	Time instant (s)
S	Sensibility matrix (dimensionless)
S^o	Orthogonalized matrix (dimensionless)
S_{max}	Column of the previous matrix with greater magnitude (dimensionless)
s	Partial derivative
s'	Coefficients of Sensibility matrix (dimensionless)
x	Dimensionless position in the bed variable
y	Operating condition
z	Position in the bed (m)

Subscripts and superscripts

A	Component in the feed stream
B	Component in the feed stream
E	Eluent
F	Feed
i	Number of performance indicator
i	Component
j	Section
n	Number of time instants
p	Number of operating conditions
R	Raffinate
S	Solid
v	Number of elements of the vector
X	Extract

Greek symbols

α	Number of mass transfer units (s^{-1})
ε	Bed porosity (dimensionless)
γ	Ratio between fluid and solid interstitial velocities (dimensionless)
θ	Performance indicator
τ	dimensionless time variable (dimensionless)

and the importance of considering the dynamic behavior of the unit for control and optimization purposes. The work reported in this study can give useful information and guidelines in SMB design, optimization and control tasks.

1.1. System description

The True Moving Bed adsorption unit is a well-known system. It was already demonstrated that the more complex system, Simulated Moving Bed, can be represented by the TMB approach (Pais et al., 2000). In this work we used the TMB approach to apply the orthogonalization based method (described in Section 2). The TMB system dynamics was characterized through the step perturbation analysis. A schematic representation of the TMB operation is presented in Fig. 1. The system consists in the countercurrent flows

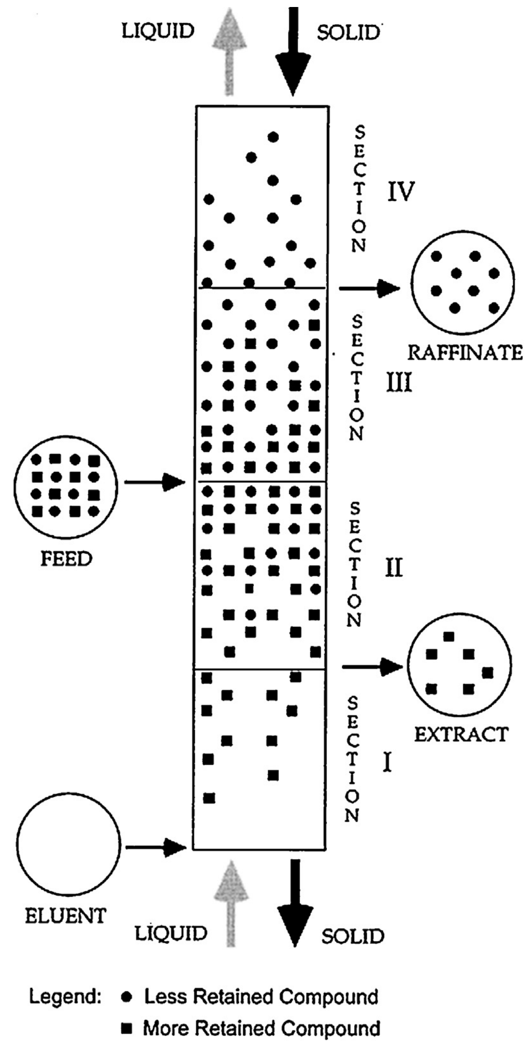

Fig. 1. True Moving Bed adsorption unit representation. Adapted from Pais et al. (2000).

of liquid (eluent) and solid phases (adsorbent). This leads to a liquid phase richer in the less retained compound. The less adsorbed compound is collected at the raffinate stream, while the stronger retained compound is obtained at the extract stream. As can be observed in Fig. 1 each section of the column plays a different role in the system separation. Sections II and III are responsible for the separation between the less and stronger adsorbing compounds, while sections I and IV are responsible for the regeneration of the adsorbent and eluent respectively.

The case study adopted was the bi-naphthol enantiomers separation using 3,5-dinitrobenzoyl phenylglycine bonded to silica gel as adsorbent and heptane-isopropanol as eluent. The system was previously studied in a pilot plant by Pais et al. (1997).

2. Methodology

In this section a method to analyze the influence of the operating variables in the dynamic response of a true moving bed is presented. The mathematical model of the process described in Section 1 is also presented.

2.1. Operating variables dynamic analysis

It is well known that each process variable has different effects on the process response. In process control and optimization it