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Enhanced performance of a three-zone simulated moving bed chromatography for separation of succinic acid and lactic acid by simultaneous use of port-location rearrangement and partial-feeding

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ABSTRACT

The performance of a three-zone simulated moving bed (SMB) chromatographic process for separation of succinic acid and lactic acid has been improved to a certain extent in previous researches by applying either a partial-feeding (PF) or a port-location rearrangement (PR) to its operation. To make a further improvement, the strategy of applying both PF and PR simultaneously to the three-zone SMB operation was proposed in this study. The results from both equilibrium-theory analysis and detailed simulation proved that the proposed strategy, which was called PF–PR in this article, had the benefit of a synergy between the individual merits of PF and PR in the three-zone SMB performance. As a consequence, the PF–PR mode could surpass the PF and the PR modes by a wide margin and the classical mode by a dramatic margin in the aspects of separation performance and throughput.

1. Introduction

Succinic acid has been credited as one of the industrially important organic acids because it can serve as a starting material for the production of a variety of valuable commodities such as detergents, pharmaceuticals, and antibiotic [1–3]. Due to such a high value and wide usefulness of succinic acid, its production with high economical efficiency has become a main interest in the related industries.

One of the latest methods for succinic-acid production was to utilize a series of fermentation and nanofiltration processes [3], which was confirmed to be effective in obtaining succinic acid. However, the final output from the nanofiltration processing was reported to include lactic acid as well as succinic acid [3], which has necessitated the application of an additional process that could be well suited for separation between succinic acid and lactic acid. This issue has recently been handled by a three-zone simulated moving bed (SMB) chromatographic process based on a classical structure and a classical operation mode (Fig. 1a) [4]. Although the three-zone SMB process in Fig. 1a was successful in continuous separation of the two organic acids, a further improvement in its performance must be a key requirement for ensuring the economic feasibility of the aforementioned succinic-acid production. It will thus be a task of great significance to devise a highly effective strategy for maximizing the performance of the three-zone SMB in Fig. 1a.

When it comes to such topic, it is worth mentioning that either a partial-feeding (PF) or a port-location rearrangement (PR) has previously proved to be effective in improving the performance of a three-zone SMB [5–8]. However, it seems that there is still room for improvement in the three-zone SMB based on either the PF or the PR strategy (Fig. 1b and c).

To make a far more improvement in the three-zone SMB performance than that based on either the PF or the PR, it is quite worth considering the simultaneous application of the PF and the PR to the three-zone SMB operation, which will be called PF–PR strategy hereafter in this article (Fig. 1d). However, no previous studies have hitherto attempted to apply such a PF–PR strategy to the three-zone SMB for binary separation.

The aforementioned work will be carried out in this study for the first time. A matter of primary concern in this work is whether the proposed PF–PR strategy can have the benefit of a synergy between the individual merits of the PF and the PR in the three-zone SMB performance. To investigate this issue, the three-zone SMB based on the PF–PR strategy will be compared with that based on either the PF or the PR in terms of separation performance. The physical basis for the results of such a comparative study will be elucidated using both equilibrium theory and detailed simulation. In addition, a meaningful dimensionless parameter that is efficient in tracking

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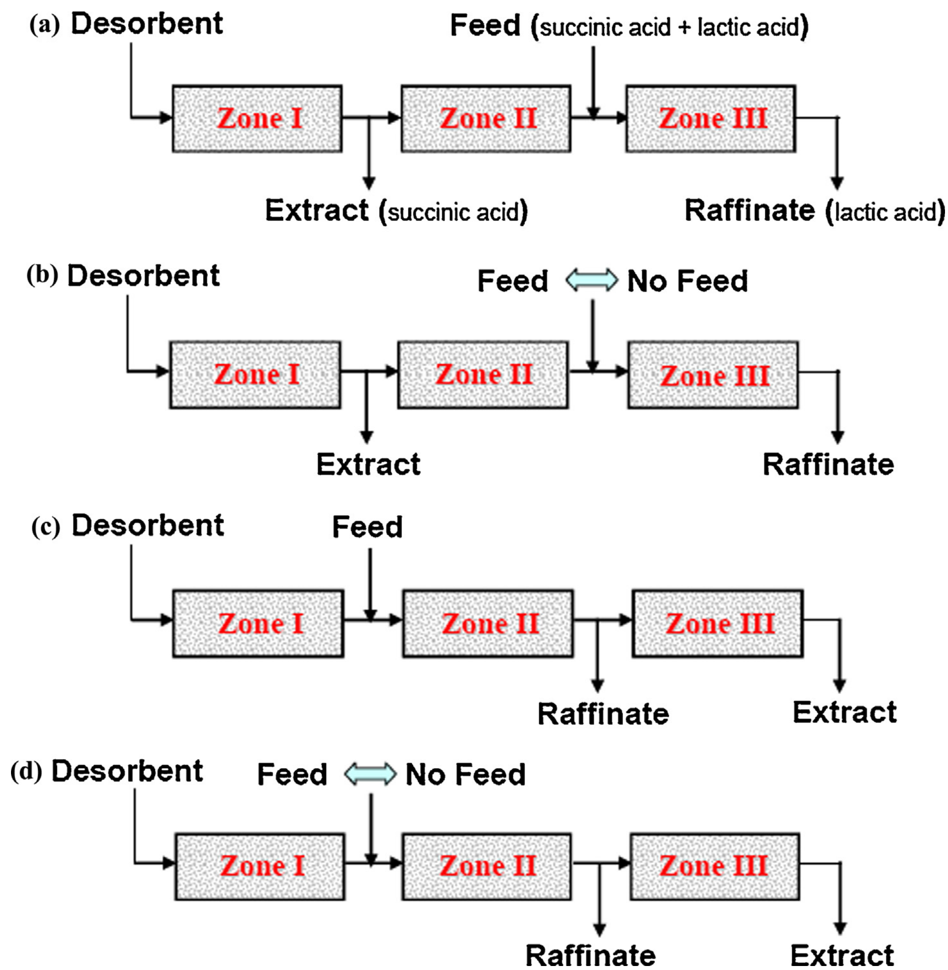

Fig. 1. Schematic diagrams of (a) the previously reported chromatographic process for separation of succinic acid and lactic acid (classical three-zone SMB), (b) a three-zone SMB based on the partial-feeding (PF) strategy, (c) a three-zone SMB based on the port-location rearrangement (PR) strategy, and (d) a three-zone SMB based on the PF–PR strategy (simultaneous use of PF and PR). Switching of ports in the SMB is not shown.

the position of front or tail of each solute band at cyclic steady state will be formulated and further, its mathematical expression will be derived for each of the three-zone SMBs based on classical, PF, PR, and PF–PR modes. The resulting dimensionless parameters for the four different modes will then be compared mathematically and graphically in order to investigate the relative superiority of the proposed PF–PR mode over the other modes. Finally, the conclusion from such investigation will be verified again by comparing the three-zone SMBs based on all the above-mentioned modes (classical, PF, PR, and PF–PR) in terms of the highest throughput attainable under the same purity requirement.

2. Theory

2.1. Roles and requirements of separation zones in SMB process

In general, the separation performance of an SMB process is determined mostly by the migration behaviors of solutes in the two zones that are located in both sides of the feed port [9]. These two zones have been referred to as *separation zones* in the literature [7,9]. Between the two zones, the separation zone located upstream from the feed port is denoted as *S-a* (Fig. 2), which fulfills the task of preventing a low-affinity component (A) from approaching the outlet port for collecting its opponent component as an extract product. The other separation zone located downstream from the feed port is denoted as *S-b* (Fig. 2), which fulfills the task of preventing a high-affinity component (B) from approaching the outlet port for collecting its opponent component as a raffinate product.

Since the separation zones play a critical role in SMB separation, a proper determination of the operating parameters associated with such zones is a matter of importance in the design of an SMB process. It was reported that such task can be facilitated by

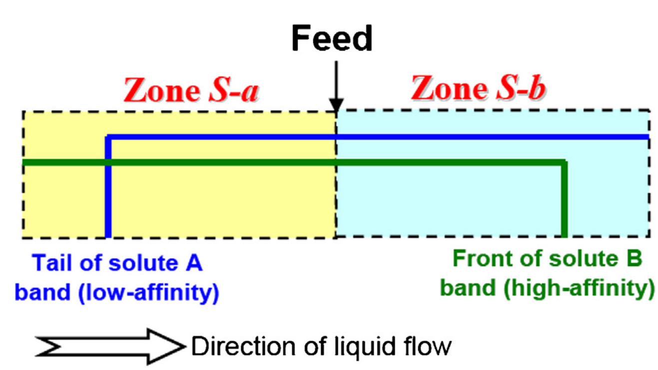

Fig. 2. Illustration of the roles of separation zones in SMB chromatographic process. Zone *S-a* is the separation zone in charge of preventing a low-affinity component (A) from approaching an extract product. Zone *S-b* is the separation zone in charge of preventing a high-affinity component (B) from approaching a raffinate product.