Continuous Chromatographic Process Based on SMB Technology

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The Problem

The conventional simulated-moving-bed (SMB) adsorption process has been very effective for the separation of a mixture into two parts. If the desired component is the strongest or the weakest adsorptive in the mixture, one will be able to obtain a clean product stream (with desorbent) under proper operating conditions. Such operating conditions can be predicted, as a first approximation, by an equilibrium theory based on constant selectivity adsorption isotherm as discussed by Storti et al. (1989, 1993, 1995), Mazzotti et al. (1994, 1996, 1997), and Chiang (1998a,b). The prediction of such an equilibrium model has also been confirmed experimentally (Mazzotti et al., 1994, 1996).

However, the conventional four-section SMB adsorption process cannot produce a clean product stream if the desired component is neither the strongest nor the weakest adsorptive. According to the common wisdom, one can use two SMB adsorption processes in succession, one for the removal of the stronger components and the other for the weaker components, to solve such a problem as illustrated in Figure 1. In this figure, the letter M stands for the intermediate component desired, while the streams S and W are for the stronger and weaker adsorptive, respectively. For most cases, the same adsorbent and desorbent will be employed in both SMB processes, but there are two possible ways to arrange the two SMB processes, as suggested by Figure 1. Naturally, the proper operating conditions will be different for the two designs.

Equilibrium Theory

The steady-state operation of a four-section SMB adsorption process is, in principle, equivalent to that of a true countercurrent (TCC) adsorption unit. Each of these two SMB processes can be considered as a four-section TCC adsorption unit, as illustrated in Figure 2. If these units are operated properly, that is, according to the complete separation conditions required by the equilibrium theory (Storti et al., 1993; Mazzotti et al., 1994, 1996; Chiang, 1998a,b), the recycled fluid and solid streams should be free of any feed components. In other words, the solid stream recycled from section 1 to section 4, as well as the fluid stream recycled from section 4 to section 1, should contain nothing but the desorbent. These conditions have been shown to be necessary for the complete separation of the feed stream into streams S and (M,W), and for the (M,W) stream into streams M and W.

If this is so, the recycled solid and fluid streams of the two TCC units can be connected as suggested by the dotted lines shown in this figure. With such a connection, these two four-section TCC units are then linked into a single eight-section TCC unit, as illustrated in Figure 3.

As there are two ways to operate the two SMB units in series, there will be two ways to combine the TCC units. They differ only in the ordering of the input and output junctions. For both cases, there will be two input junctions for the de-

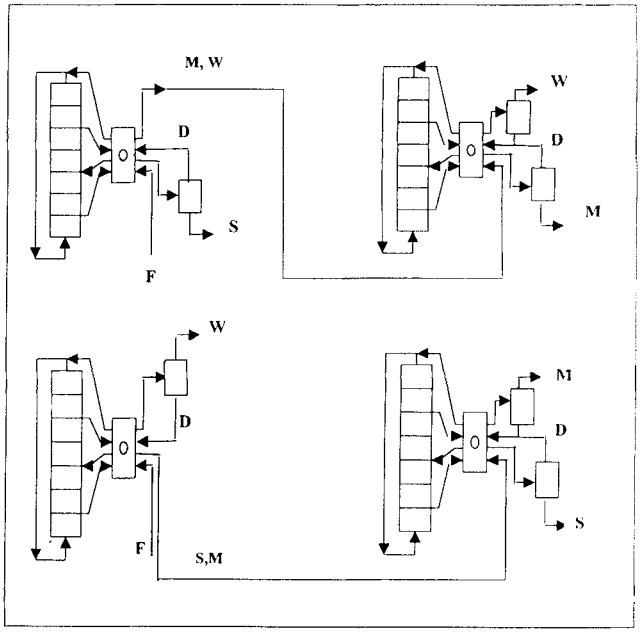

Figure 1. Two possible ways of operating two SMB processes to separate components into three cuts.

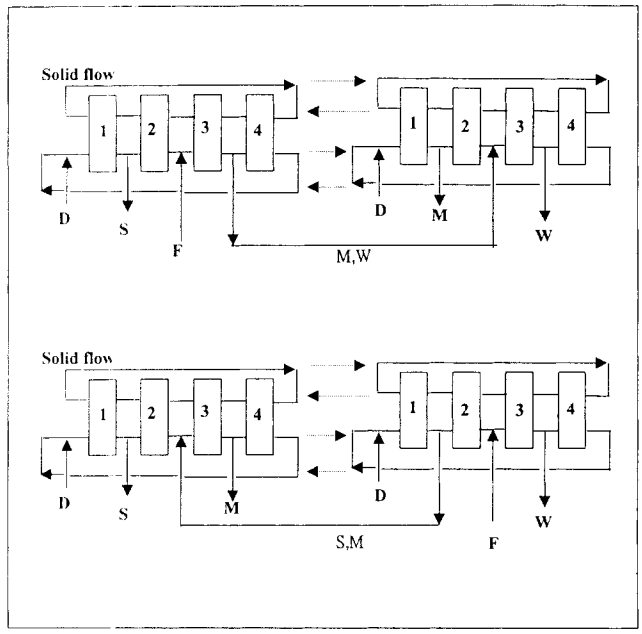

Figure 2. Connections between equivalent four-section TCC adsorption units to separate a feed into three cuts.

Each flow chart corresponds to an arrangement of the SMB processes given in Figure 1.

orbent and one input junction for the feed mixture. Three output streams, marked, respectively, as S, M, and W for the strong, intermediate, and weak adsorptives, are obtained. Another pair of input and output junctions is supplied for the internal recycle stream.

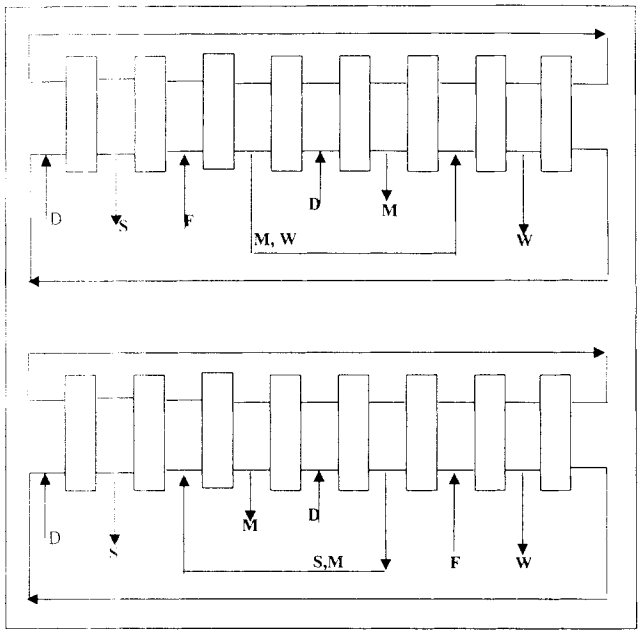

Figure 3. Combined eight-section TCC adsorption units obtained by reconnecting the recycle streams as in Figure 2.

There are again two possibilities corresponding to the two arrangements of the SMB processes.

Being a single TCC unit, it can be realized by the same SMB technology, even when there are eight instead of four sections. The only difference is the need of a few more ports to the rotary switching valve. On the other hand, three product streams are now obtained directly. By adjusting the desorbent inputs to balance the difference in the recycled fluid streams, the eight-section TCC unit will be operated exactly the same way as two four-section ones. In other words, if a pure intermediate stream (plus the desorbent) was obtained by the dual TCC unit design, the same stream would be obtained with the new eight-section unit.

The same concept can be easily extended to more complicated systems. For example, a 12-section TCC unit will be able to split the feed into four cuts and a 16-section TCC unit will produce five output streams. In other words, as long as a multisection TCC adsorption unit can be realized by the SMB technology, a continuous chromatographic separation will be possible. The only limitation to such an extension will be the physical constraint on the maximum number of ports in a rotary valve.

A continuous chromatographic separation process is very important, since the preparative chromatography has been the key means of separation for the biochemical and pharmaceutical industries. However, except for the early proposal of an annular chromatographic system (Wankat, 1984), there has been no practical process design that can perform a chromatographic separation in continuous mode. With the multisection TCC adsorption design proposed here, the proven SMB technology can be applied to realize a continuous chromatographic separation process.

The equilibrium theory previously developed for the four-section SMB processes may then be extended to identify the proper operating conditions under which a complete separation is achieved. For a single four-section TCC adsorption unit, we had four operation parameters to deal with. By taking the output of one unit as the input to the other, a degree of freedom is lost. Therefore, only seven independent operation parameters can be identified for the combined eight-section unit. Constraints on two out of the seven operation parameters can be identified independently of the others. However, the other five parameters are highly coupled, and the analysis of the equilibrium theory will not be as straightforward as one might hope. Furthermore, two possible designs have been proposed. The benefit of one over the other can only be determined after a complete analysis based on the equilibrium theory. Such an analysis is now in progress and will be reported in the future.

Conclusion

A new design for continuous chromatography to separate the components in a mixture into more than two distinct parts has been proposed. The proposed design can be easily realized based on the proven SMB technology. The only limit on the number of parts obtainable is the number of ports available in a rotary valve. The feasibility of the proposal can be proved based on the complete separation conditions previously identified for a four-section SMB process using the equilibrium theory. The same theory can also be used to determine the exact range of operation parameters for the fractionation of individual components.

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