445d Optimal Configuration, Design and Operation of Hybrid Batch Distillation/Pervaporation Processes

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Distillation is the most commonly used technique for separating liquid mixtures within the chemical industries despite being an energy and capital intensive process. Many mixtures commonly encountered in the fine chemical and pharmaceutical industries are, however, difficult or impossible to separate by normal distillation due to azeotropic behaviour, tangent pinch or low relative volatilities. Pervaporation has been hailed as an alternative to distillation for such mixtures as the separation mechanism is different, relying on differences in solubility and diffusivity between the components in the mixture and not vapour-liquid equilibrium as in distillation. Recently, hybrid processes have been proposed where a distillation column unit and a pervaporation unit are integrated into one process. In such a process, the shortcomings of one method are outweighed by the benefits of the other, allowing for significant savings in terms of energy consumption and cost. Although the optimisation of design and operation of continuous hybrid distillation/pervaporation processes has been attempted before, this is the first time the simultaneous optimisation of configuration, design, and operation is considered and it is in this work applied to batch hybrid distillation/pervaporation processes.

The two units can be integrated in different ways; the pervaporation unit can be positioned before the distillation column, after the column, or fully integrated. Depending on the particular separation task, the configuration, design and operation of a hybrid should be optimised to achieve the most suitable performance. Eliceche et al. (2002) carried out optimisation studies of operating conditions for a continuous hybrid distillation/pervaporation system consisting of an azetropic distillation column connected via a side stream to a pervaporation unit. They solved the optimisation problem by minimising the operating costs, however, they did not consider the design or configuration of the hybrid system. Szitkai et al. (2002) optimised the design and operation of a continuous hybrid dehydration system using an MINLP model to minimise the annual operating costs of a single, post-distillation, hybrid configuration. Recently, Kookos (2003) proposed a methodology for the structural and parametric optimisation of continuous hybrid separation systems. He described the superstructure of the hybrid process using a simplified steady-state mathematical model where it was assumed that all streams taken from, or returned to, the distillation column were vapour streams. The methodology is therefore not suitable for other membrane processes, such as pervaporation, or for dynamic systems, such as batch processes.

This paper considers for the first time, the simultaneous optimisation of configuration, design and operation of hybrid batch distillation/pervaporation processes by considering all possible process structures. The overall problem is formulated as a mixed integer dynamic optimisation (MIDO) problem. The optimisation strategy comprises of an overall economics index that encompasses capital investment, operating costs and production revenues. Furthermore, rigorous dynamic models developed from first principles for distillation and pervaporation are used. Several case studies for the separation of homogeneous azeotropic mixtures are presented. It is found that fully integrated hybrid configurations may in some cases be economically favourable when compared to post and pre-distillation configurations, however, these configurations may be more complex to operate and control. Recommendations for when to use which configuration will be given by considering profitability, operability and controllability.

References

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