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Synthesis of dividing-wall columns (DWC) for multicomponent distillations—A systematic approach

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ABSTRACT

Dividing-wall columns (DWC) are intensified distillation systems for multicomponent separations. They have the potential to save significantly both energy and capital costs than conventional simple column configurations. In this paper, it is shown that the DWC columns can be systematically generated from the conventional simple column configurations. Because of the simple column sequences with sharp splits are the simple and widely studied conventional schemes for multicomponent distillation, the purpose of this work is to formulate a procedure for systematic synthesis of DWC columns for such simple conventional schemes. A four-step procedure is formulated which systematically generates all the possible DWC columns from the simple column sequences. First, the subspace of the original thermally coupled configurations corresponding to the simple column configurations is generated. Then, the subspace of the thermodynamically equivalent structures corresponding to the original thermally coupled configurations is produced. Finally, the subspace of the DWC columns corresponding to the thermodynamically equivalent structures is achieved. An example of quaternary distillation is used to illustrate the synthesis procedure which is applicable to a mixture with any number of components.

Keywords: Dividing-wall column; Systematic procedure; Distillation synthesis; Thermal coupling

1. Introduction

Distillation is and will still be the main workhorse in many process industries, including chemical, petrochemical, biochemical and bioenergy among others. However, distillation is also the largest energy consumer among process units and simultaneously needs a large capital investment. Moreover, in many industrial separation problems, the mixtures usually involve multiple components and often need several distillation columns in the separation processes. Therefore, research on process synthesis to find new distillation systems with the potential to significantly reduce both energy consumption and capital investment is ever becoming important. The significance of such research problem is ever becoming crucial due to that a considerable reduction of CO_2 is simultaneously achieved by such new distillation technology, which greatly contributes to sustainable development in terms of saving resources and protecting environment.

For a multicomponent distillation, the traditional designs of simple column configurations use $n-1$ columns and $2(n-1)$ condensers and reboilers for an n-component separation (Henley and Seader, 1981). Each column implements one of the $n-1$ sharp splits for an n-component distillation. Such simple column configurations have the intrinsic separation inefficiency and suffer from both high energy consumption and large capital investment. It is known that the number of columns and the number of heat exchangers (condensers and reboilers) in a distillation system represent not only the final equipment costs but also the installation costs in the final plant construction. The sizes of columns and heat exchangers in a distillation system are directly related to the energy amount consumed for the specified separation which attribute to the energy efficiency of the separation process (Rong and Turunen, 2006a). Therefore, novel distillation systems must achieve the goal in twofold simultaneously: first, they can significantly reduce energy consumption, and second they

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should have a reduced number of pieces of equipment. This calls for the intensified distillation systems for achieving the savings in energy and capital costs simultaneously.

One type of novel distillation systems for multicomponent separations is the dividing-wall columns (DWC), which take the advantage of process intensification that reduce both the number of columns and the number of heat exchangers compared to conventional configurations. The DWC columns for ternary separations have been widely studied, and many applications have demonstrated that energy consumption can reduce by 30–50% compared to conventional columns (Becker et al., 2001; Greene, 2001; Kaibel and Schoenmakers, 2002; Schultz et al., 2002). It must be indicated that the several DWC columns for ternary distillations have been figured out by chaotic creative activities from different inventors. As industrial separation problems very often involve four or more components, for such problems, due to complexity, it is impossible to find all the feasible DWC columns by inventive activities. On the other hand, industrial experience shows that the optimal system for a specific application can only be guaranteed by predefining all of the feasible options (Kaibel and Schoenmakers, 2002). Therefore, like synthesis of traditional distillation configurations and thermally coupled configurations, there need synthesis method for systematic generation of the feasible DWC columns for multicomponent mixtures. There were few works in the literature reported a few specific DWC columns for multicomponent separations (Kaibel, 1987; Christiansen et al., 1997; Agrawal, 2001; Halvorsen and Skogestad, 2003). Like for ternary mixtures, these specific DWCs were obtained by some inventive activities.

In this paper, we have presented a procedure for systematic synthesis of the DWCs for traditional distillation configurations with sharp splits. It is shown that the DWC columns are finally generated from the thermodynamically equivalent structures of the corresponding thermally coupled configurations. It is worth to note that the thermally coupled configurations and the thermodynamically equivalent structures can be synthesized for distillation sequences with both sharp and sloppy splits following different methods (Agrawal, 1996, 2000, 2003; Rong et al., 2003; Rong and Turunen, 2006b; Caballero and Grossmann, 2003, 2004). In this work, the focus is on the DWC columns for the thermally coupled configurations from simple column sequences with only sharp splits. For multicomponent mixtures, the simple column sequences with only sharp splits constitute a unique subspace which was widely studied during early stage of distillation synthesis (Thompson and King, 1972; Henley and Seader, 1981; Nadgir and Liu, 1983; among many others). In the following, we will show that a unique subspace of the DWC columns can be generated from such a widely studied subspace of the simple column sequences following the proposed synthesis procedure.

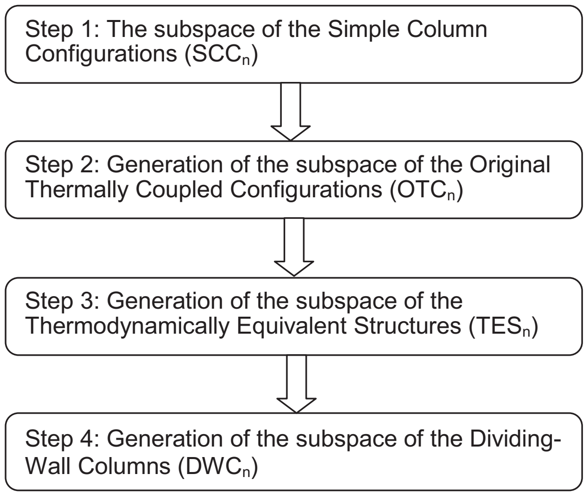

Fig. 1 – A systematic procedure for synthesis of dividing-wall columns for multicomponent distillations.

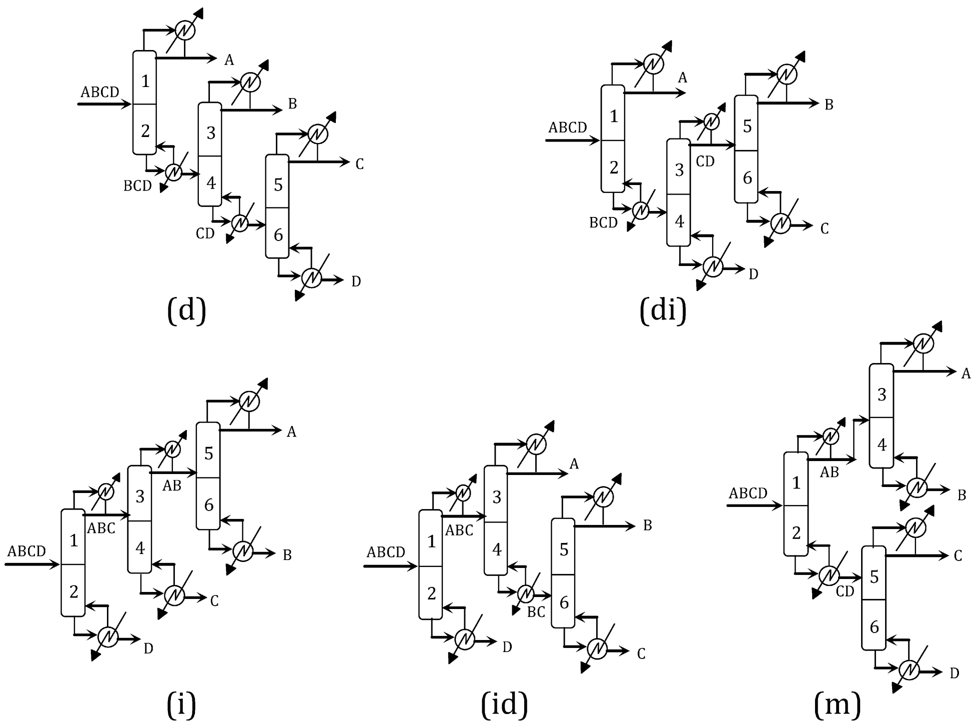

Fig. 2 – The five simple column configurations (SCC_n) for quaternary mixtures.