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# SYSTEMATIC SYNTHESIS OF DIVIDING-WALL COLUMNS FOR MULTICOMPONENT DISTILLATIONS

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**Abstract**
Dividing-wall columns(DWC) are intensified distillation systems for multicomponent separations. They have the potential to save both energy and capital costs significantly than conventional simple column configurations. The several DWC columns for ternary distillations have been figured out by some creative activities from different inventors. Recently they have gained the momentum to be widely implemented in industrial separation processes. 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. In this work, a procedure for systematic synthesis of DWC columns for multicomponent distillation is presented. Starting from the conventional simple column configurations for the separation of a multicomponent mixture, a four-step procedure is formulated which systematically generates all the possible DWC columns. First, the subspace of the possible thermally coupled configurations corresponding to the simple column configurations is generated. Then, the subspace of the possible thermodynamically equivalent structures corresponding to the thermally coupled configurations is produced. Finally, the subspace of the DWC columns corresponding to the thermodynamically equivalent structures is achieved. The method is simple, easy-to-use and can systematically synthesize all the possible DWC columns. 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, synthesis 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 significant. 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. 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[1]. Therefore, novel distillation systems must achieve the goal in twofold simultaneously: First, they can significantly reduce energy consumption, and second they 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[2]. However, the DWC columns for four or more component mixtures have not been studied widely. There were few works in the literature reported a few specific DWC columns for multicomponent separations[3-5]. Like for ternary mixtures, these specific DWCs were obtained by some inventive activities, none of them was concerned with a procedure to systematically synthesize all of the possible DWCs.

The main objective of this work is to present a procedure for systematic synthesis of DWC systems for multicomponent distillations. The distinct feature of a DWC column is that it has less than n-1 columns and less than 2(n-1) heat exchangers (condensers and reboilers) than the conventional configuration. To systematically synthesize the DWC columns, there needs an approach to coordinate the separation tasks and rearrange the column sections and heat exchangers in a distillation configuration. This is achieved through the synergy of the separation tasks by thermal couplings and then rearranging the column sections between the column units. On the basis of this, a procedure is formulated which is presented as follows.

## 2. Synthesis Procedure

The procedure consists of four steps to produce the DWC columns step-by-step. The first step is to draw the conventional simple column configurations (SC). The second step is to generate the original thermally coupled configurations (OTC) from the corresponding SCs. The third step is to generate the thermodynamically equivalent structures (TES) from the corresponding TESs. Finally, the fourth step is to produce the dividing-wall columns (DWC) from the corresponding TESs. In the following, the procedure is illustrated for the synthesis of DWC columns for quaternary mixtures, which is applicable to mixtures with any number of components.

### *2.1 Step 1: The Simple Column Configurations (SCs)*

The procedure starts by drawing all the possible simple column configurations. It is known that for an N-component separation, the number of simple column configurations can be predicted with the equation developed by Thompson and King[6]. For a four-component mixture, there exist five simple column configurations, which are illustrated in Figure 1.

### *2.2 Step 2: The Original Thermally Coupled Configurations (OTCs)*

In each simple column configuration, 2(N-1) heat exchangers are employed, N heat exchangers are associated with the N products, while N-2 are associated with the submixtures of two or more components. When only sharp splits are considered, 2(N-1) columns sections are needed.

Each original thermally coupled configuration can be obtained from the corresponding simple column configuration by eliminating those condensers and/or reboilers associated with submixtures of two or more components, while bidirectional thermally coupled vapour and liquid streams are introduced. For configurations with more than one submixture, it is possible to eliminate the corresponding heat exchangers one at a time or all at the same time. For example, for the configuration of the direct separation sequence shown in part (d) of Figure 1, three original thermally coupled configurations (OTC) are generated, which are shown in Figure 2. In total, 15 original thermally coupled configurations can be generated for the SCs in Figure 1 (A, B, C, D-components in decrease volatility; 1 to 6-column sections).

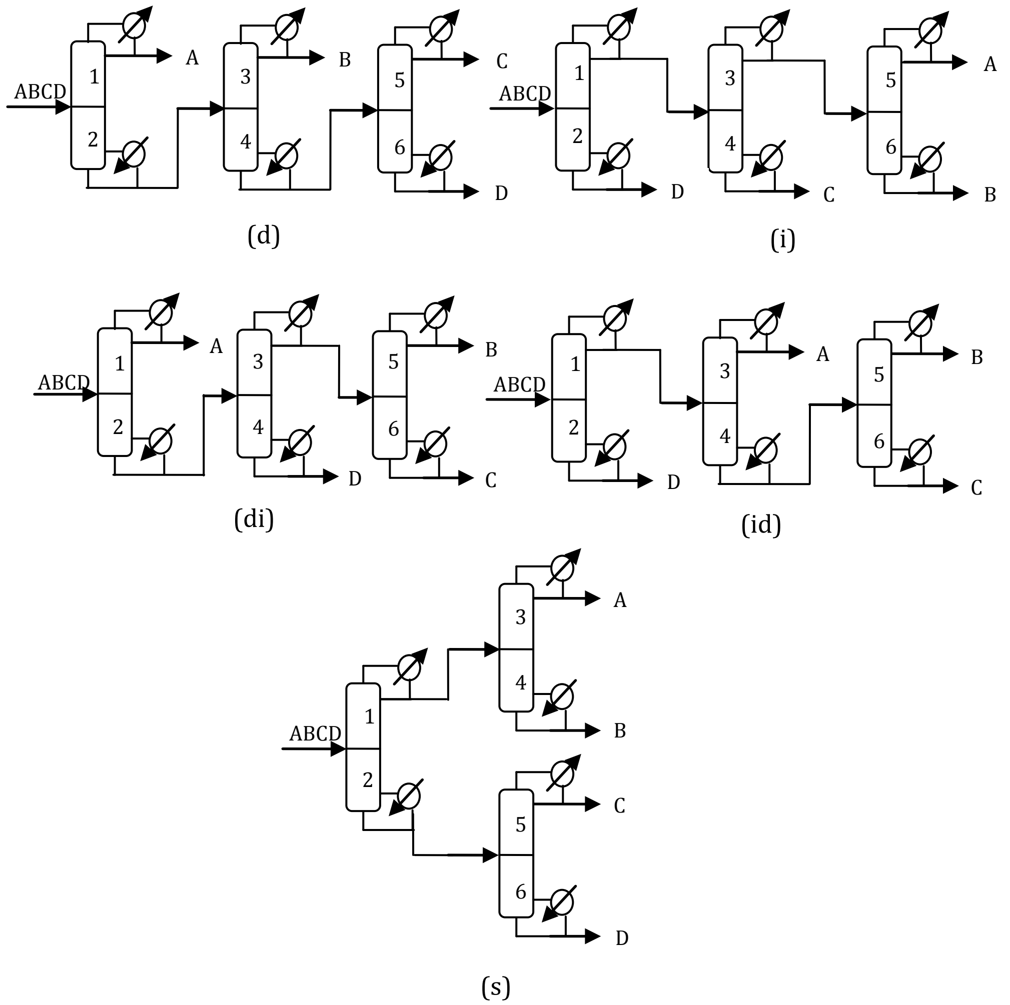


**Figure 1.** The five simple column configurations for quaternary mixtures

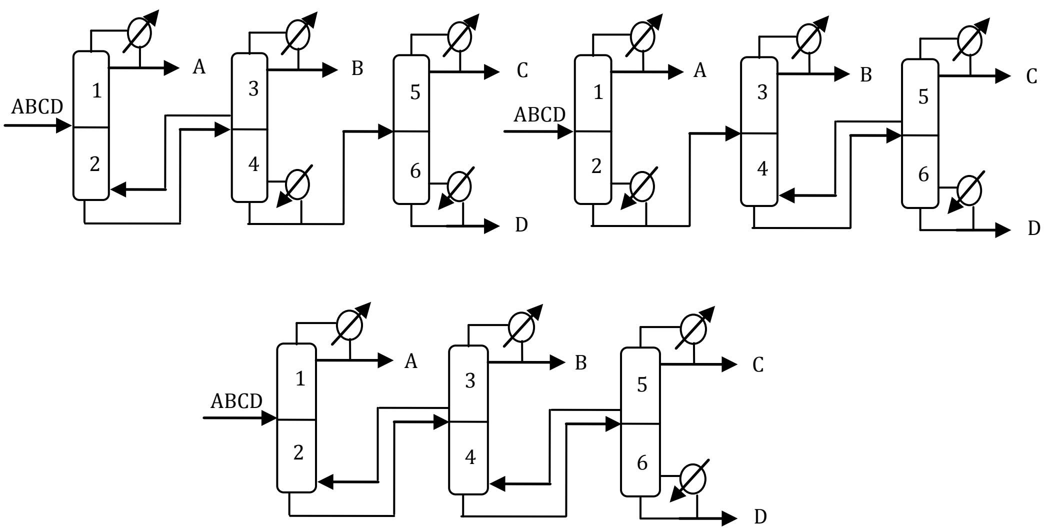


**Figure 2.** The original thermally coupled configurations for the SC in Figure 1(d)

### *2.3 Step 3: The Thermodynamically Equivalent Structures (TESs)*

From the original thermally coupled configurations, the thermodynamically equivalent structures can be generated by rearranging the column sections through the movable column sections. The number of movable sections is equal to the number of thermal couplings introduced in an OTC. For an N-component mixture, the number of thermodynamically equivalent structures (TES) of a given OTC can be predicted using the formula developed by Rong et al.[7]. Figure 3 presents the TESs generated from the OTCs in Figure 2 (A, B, C, D-components in decrease volatility; 1 to 6-column sections).

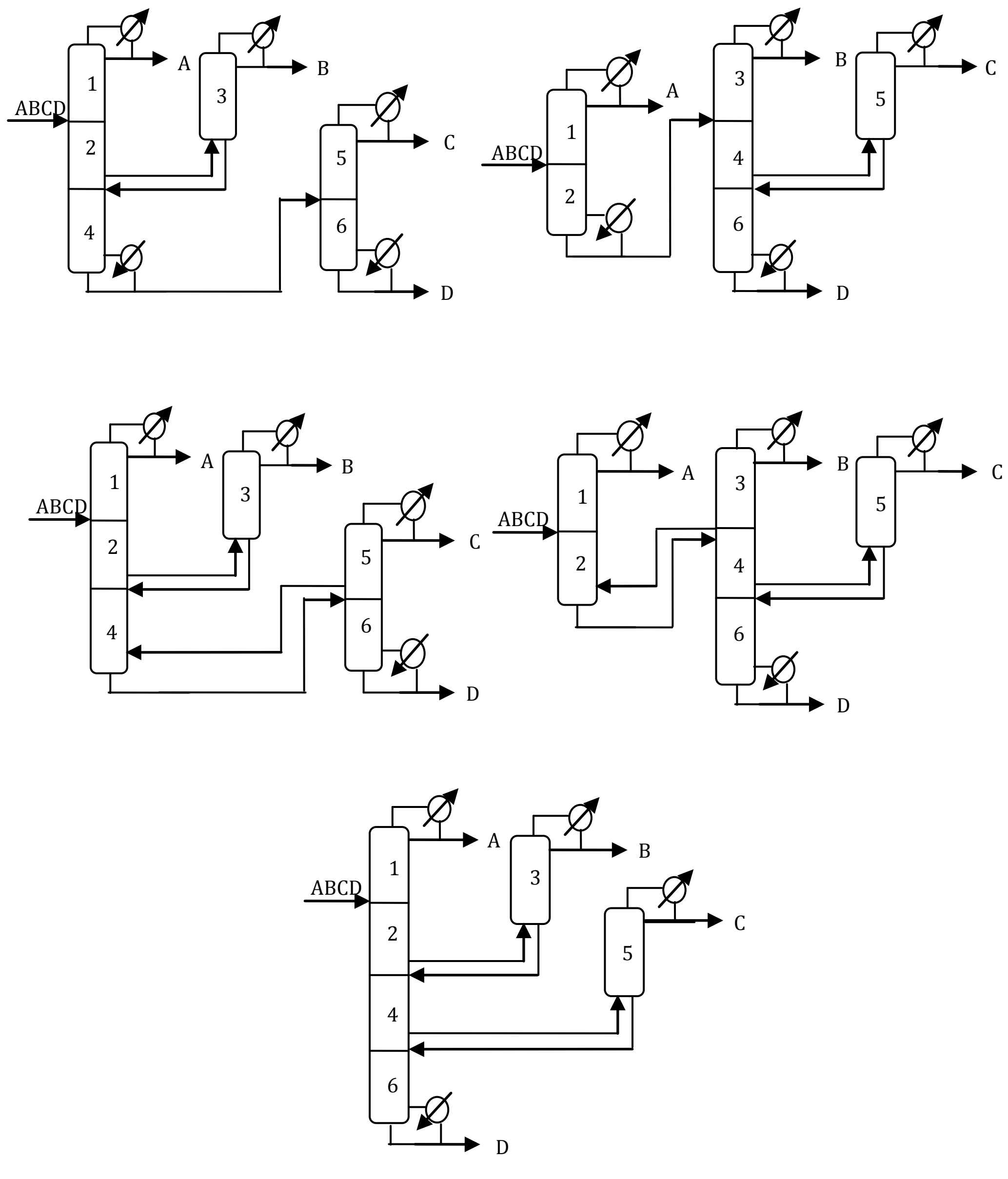


**Figure 3.** The thermodynamically equivalent structures generated from OTCs in Figure2

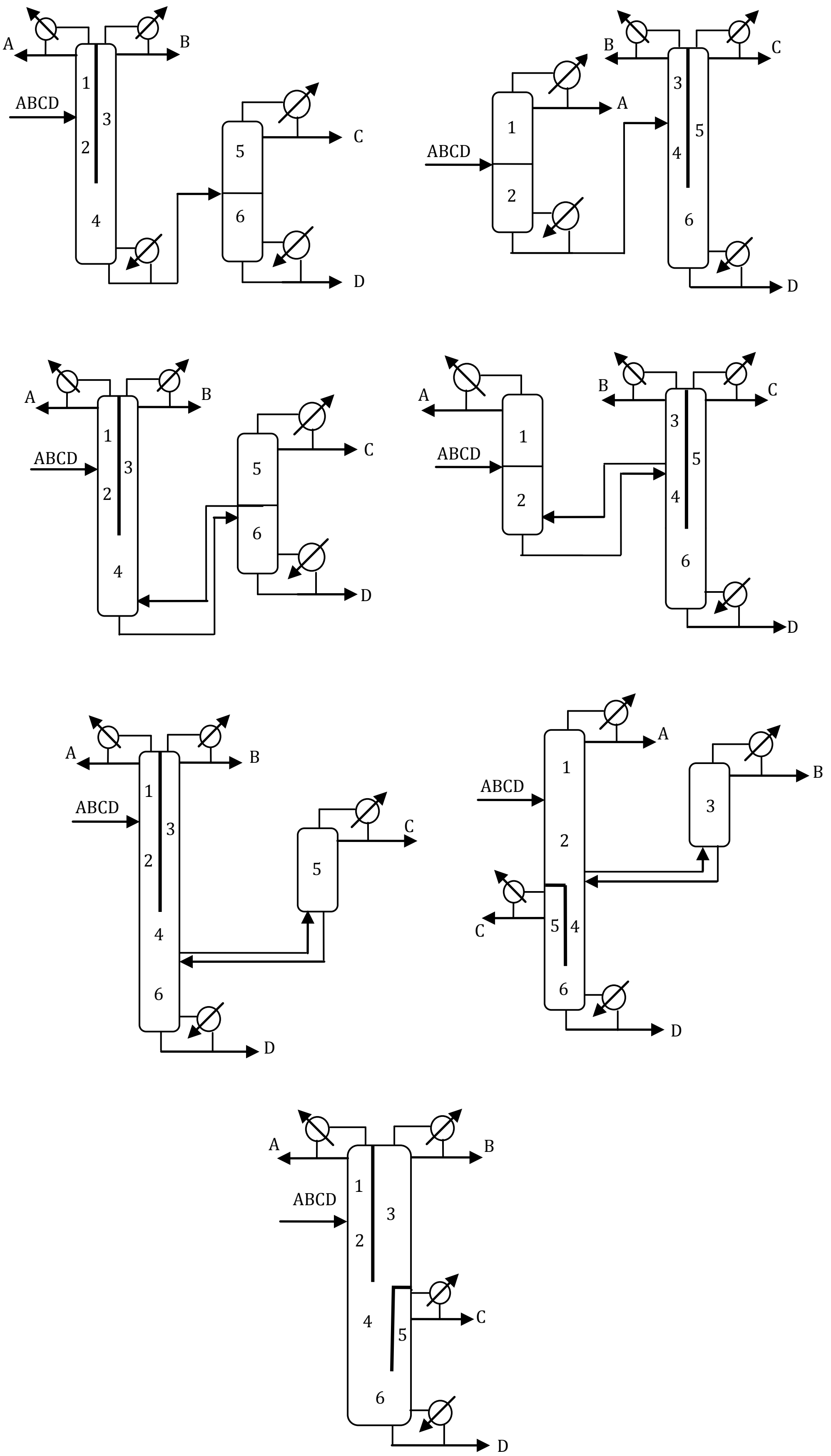


**Figure 4.** The dividing-wall columns generated from the TESs in Figure 3

*2.4 Step 4: Generation of the Dividing-Wall Columns (DWCs)*

Now, from the thermodynamically equivalent structures generated from the OTCs, it is possible to generate the corresponding Dividing-Wall columns (DWC). It is observed that, in each of the TESs in Figure 3, there is at least one column with only one-section which is thermally linked with the other column through the bidirectional vapour and liquid streams. Such a side column with only one-section is generally functions as to purifying a product of an intermediate volatile component of the feed mixture. In our earlier work to generate the distillation systems with less than N-1 columns[8], such a side column was simply eliminated and left one of the thermal coupling streams as the side-stream product. In many cases, this will inevitably incur the impure side-stream products. Now, such a side column with one-section can be incorporated into its thermally linked column through a dividing-wall which can produce the dividing-wall column configurations (DWC).

It must be indicated that for those TESs with more than one one-section side column, it is possible to incorporate the side columns into the thermally linked column one at time or all at the same time. For the TESs in Figure 3, Figure 4 presents the DWC columns generated from the corresponding TESs in Figure 3. Starting from each of the simple column configurations shown in Figure 1, all of the possible DWC columns are readily produced following the above procedure.

## 3. Conclusion and Remarks

DWC columns are intensified distillation systems and have the potential to reduce both energy and capital costs significantly. They are among the most attractive options when looking for optimal distillation processes for many process industries in chemicals, petrochemicals, biochemicals and bioenergy etc. This is due to the fact that they are simultaneously fulfilling the economics and sustainability objectives. From process synthesis point of view, there calls for systematic procedure to predefine all of the possible DWCs for multicomponent separations. This will ensure that the optimal option is guaranteed for a specific application.

In this paper, a procedure for systematic synthesis of the DWC columns is presented. The procedure is composed of four steps and each one generates a subspace with different DWC alternatives. The procedure is easy-to-use and can systematically generate the DWC columns for any n-component mixture.

It is shown that there are a large number of promising DWC columns for a mixture with four or more components. This imposes further challenging and interesting research problems in many aspects in order to produce the necessary methods and knowledge to implement such novel systems in industrial processes. Among others, the most important research problems call for the shortcut and rigorous design methods, the optimization searching algorithms, the dynamics and controls, and the equipment design and construction.

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