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Dynamic behavior of the intensified alternative configurations for quaternary distillation

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ABSTRACT

Process intensification emerges as an important tool in the synthesis of multicomponent distillation configurations aimed at the reduction of the energy use and capital costs. Operational and fixed costs savings coupled with simplicity and controllability design configurations appear as an essential characteristic for industrial acceptance of intensified configurations. Following the aforementioned principles, two intensified configurations for the separation of quaternary mixture, were considered. These configurations were recognized as a valid alternative to overcome the complexity of the quaternary Petlyuk scheme.

The study of the dynamics and control properties represent an important research issue in the analysis of new configurations to prove their effective applicability. The theoretical control properties of the alternative intensified configurations were obtained using the singular value decomposition technique in all frequency domain. In order to complete the control study, the distillation schemes were subjected to closed-loop dynamic simulations. The results show that there are cases in which the intensified sequences do not only provide energy savings, but also may offer dynamic advantages in comparison to the conventional four-component scheme.

1. Introduction

Distillation is the most commonly used separation technique in the chemical and petrochemical process industries but, at the same time, it is also the most energy intensive unit operation. Distillation handles about 3% of total US energy consumption; over 90% of all product recovery and purification separations in the US, and over 95% of chemical industry consumption worldwide [1]. Data from the United States Department of Energy indicate that distillation columns, in the U.S., consume 5.07 million TJ per year; corresponding to 43% of the total installed net capacity of the 439 nuclear power plants in operation worldwide [2]. To overcome the problem of this high energy consumption, several heat-integrated and fully thermally coupled distillation systems (also called Petlyuk columns) were studied, and it has been proven that thermally coupled configurations are promising alternative energy solutions. Theoretical studies have shown that the Petlyuk scheme, for ternary mixtures separation, can achieve around 30% energy and capital cost savings, compared to conventional distillation systems. Any reduction of energy consumption will bring not only economic benefits but also environmental benefits [3–6]. Reported studies reveal that the ternary-Petlyuk column provides the maximum energy reduction in distillation columns [7]. In most cases, this separation scheme is implemented in the form of a dividing wall column (DWC), in which both columns are installed in a single shell, where all the products are separated in a single shell column.

A number of design and optimization methods for the ternary-Petlyuk column have been proposed by several researchers [8,9]. Despite the energy and capital advantages of ternary-Petlyuk configuration, its industrial application began two decades ago; the world's first ternary-Petlyuk configuration was established by BASF in 1985. In addition, understanding the control and operability issues has improved greatly. Since then, many ternary-Petlyuk arrangements have been established worldwide,

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such as in Europe, South Africa, and the US [10]. Amminudin et al. [11] noted that industrial acceptance and commercialization of Petlyuk columns by organizations such as BASF AG, M.W. Kellogg (together with BP, later known as BP Amoco), and Sumitomo Heavy Industries Co. together with Kyowa Yuka. Linde AG constructed the world's largest DWC for Sasol, an estimated 107 m tall, and 5 m in diameter. Hence, there are better prospects for Petlyuk configuration in the near future, and it might become a standard distillation configuration in chemical process industries over the next 50 years [12]. As industrial separation problems very often involve four or more components, due to complexity, it is impossible to find all the feasible DWC columns by innovative 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 [13].

It is possible to assert that, for the case of three component separations, the Petlyuk, and its equivalent DWC configuration, has the potential to save a significant amount of energy, different design methods are available, structural complexity may be overcome by using thermodynamically equivalent configurations, and moreover, the control issues may be solved [14]. It is clear that the same results are aimed for a different number of feed components. Moving from three to four components, the complexity of the Petlyuk and DWC structure increases and up to now only a few studies are focused on the possible applications of these configurations [15,16]. The focus of this work is to analyze the dynamic behavior (closed loop control policy, using PI controllers) of alternative configurations to the Petlyuk configuration for a four-component separation. These new distillation configurations were obtained following the systematic method based on four strategies as proposed by Rong [17]. The steady-state study with specific quaternary mixtures showed promising results to save both energy and capital costs when compared to the more complex quaternary Petlyuk scheme [18]. The study of the dynamics and control properties represents an important research problem in the analysis of these new configurations.

2. Alternative intensified configurations

The conventional configurations used to derive the four-component Petlyuk configuration separation are illustrated in Fig. 1. In Fig. 1a) the second and the third columns are connected by a one-way transport for the BC (OW)stream and in Fig. 1b) the BC mixture is connected by a two-way transport stream (TW).

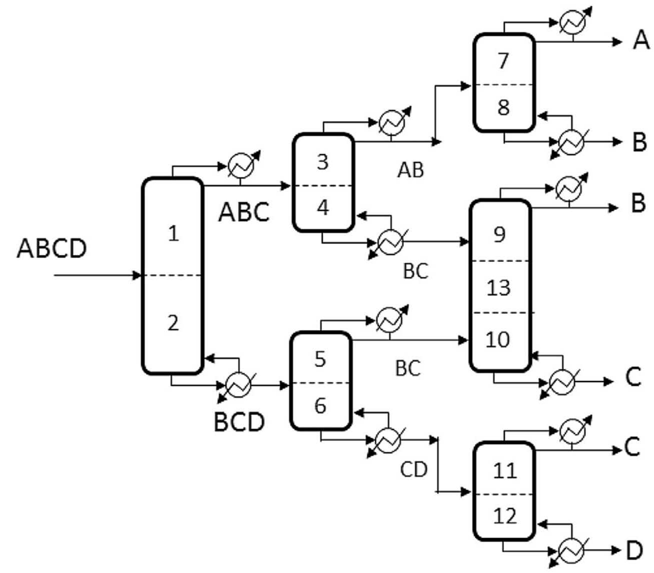

Fig. 2. The simple column configuration (SCC) for the fully sloppy separation sequence of a quaternary mixture.

The number of columns in conventional configurations is N-1, which is equal to the number of columns in any sharp conventional configurations, and which is also the minimum number of columns for any non-sharp conventional configurations [19,20]. However, Rong [21] illustrated that such non-sharp conventional configurations with N-1 columns lost the structural flexibility to produce the intensified distillation configurations with less than N-1 columns. In order to produce the intensified configurations with fewer columns, Rong [17] illustrated that the simple column configuration (SCC) representation for any non-sharp sequence is necessary as the starting point, which keeps all the structural flexibility to derive the intensified configurations. The simple column configuration for the non-sharp sequence of the quaternary intensified columns is illustrated in Fig. 2.

Starting from this SCC representation, a method to derive all the possible intensified distillation configurations with less than N-1 columns was presented; we derived five distinct alternative intensified distillation configurations for the quaternary distillation sequences [22].

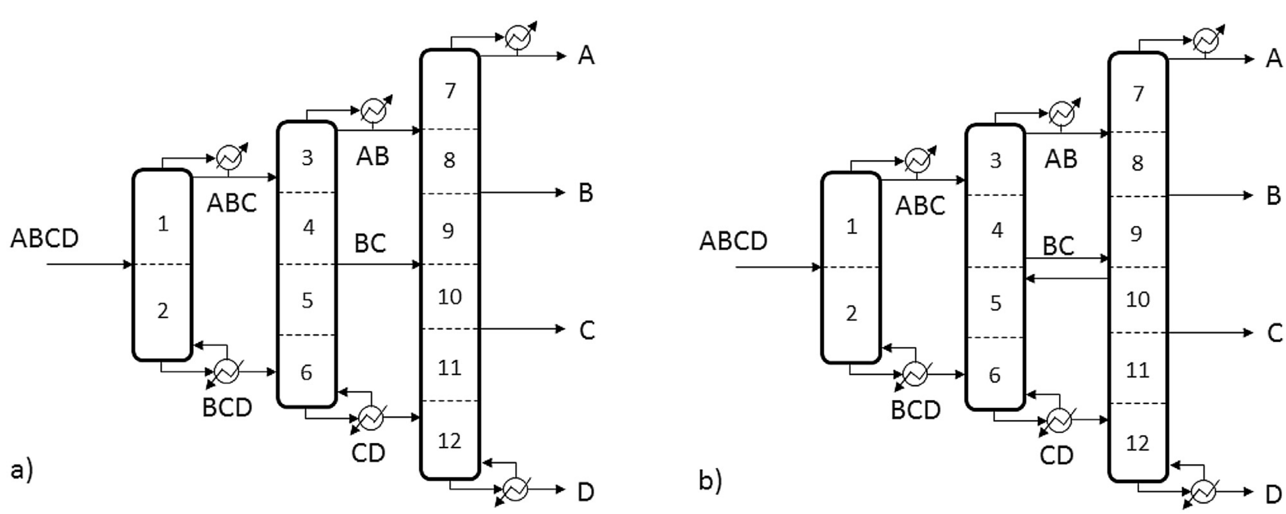

Fig. 1. The conventional configurations used to derive the Petlyuk column for four components separation: a) one-way transport for BC stream (OW); b) two-way transport for BC stream (TW).