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Design and optimization of a dividing wall column for debottlenecking of the acetic acid purification process

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ABSTRACT

The dividing wall column (DWC) has gained increasing application in a variety of chemical processes because of its potentiality in energy and capital cost savings in multicomponent separations. The main objective in this work is investigation of its use for removing the bottleneck phenomenon within the column when increasing the throughput of an existing distillation process, particularly, the acetic acid (AA) purification process. Optimal column sequence design, involving both conventional and DWC, is considered. The internal recycle flow distribution around the dividing wall was investigated as a primary optimizing variable. Several column arrangements were analyzed to show that the DWC requires less investment and energy costs than conventional distillation, the Petlyuk column, or the prefractionator arrangement.

1. Introduction

It is well-known that distillation plays an important role in the chemical process industries and consumes the largest amount of energy with an estimated 3% of the world's energy consumption [1]. Development of a new type of column and/or performance enhancement of existing distillation processes for improved energy efficiency have been imperative issues associated with distillation [2].

For ternary separations, either the direct or indirect sequences with two conventional columns are typically employed to separate the mixture according to product specifications. Although the control and operation strategy for the conventional columns is simple, it is inefficient in terms of energy due to the mixing entropy by irreversible split [3]. Therefore, various strategies have been applied to improve the energy efficiency of such distillation systems. One in particular is thermal coupling, whereby the transfer of heat is achieved by a direct contact of material flow between the columns [4–6]. Many studies confirm that the fully thermally coupled distillation system (FTCDS) or the Petlyuk column offers a great chance at reduced energy consumption [7–11]. In lieu of two condensers and two reboilers as the normal two column sequence, the Petlyuk column has only one condenser and one reboiler due to full integration of the prefractionator and main column, schematically drawn in Fig. 1a. In the Petlyuk column arrangement, reversible splits are possible and no part of the separation is performed twice, which mainly attribute superior energy efficiency for separation over other column configurations [12].

However, the Petlyuk column undergoes strong interactions between the two columns because of their thermal integration, which causes some difficulties in design and operation. To solve this problem, as well as reduce the capital cost, a vertical wall is installed in the central section of the column, dividing it into the prefractionator and the main section, as seen in Fig. 1b. This arrangement is referred to as the dividing wall column (DWC), which is conceptually the same as the Petlyuk column given the thermodynamically equivalent arrangements [6], and more than 90 applications in commercial scale are known [3].

When the throughput of an existing distillation column sequence increases, entrainment flooding may create a bottleneck in the column. The goal of a retrofit design is identification and removal of such bottlenecks [13]. Most retrofit practices in distillation have emphasized column internals that not only promote separation, but also govern the column hydraulic performance [14]. However, using better internals to debottleneck distillation columns is not the only design option, nor is it always the most cost effective [13]. In some cases, this does not improve the energy efficiency of the system and could subsequently prevent a large increase in capacity [15]. Furthermore, in the case where the column already has a high efficiency internal, the potential for capacity increases by replacing the existing column internal with a new one is very limited.

The key to a successful retrofit lies in maximizing utilization of the existing equipment, while simultaneously minimizing the new hardware so as to abbreviate capital costs. Re-arrangement of existing columns to complex column arrangements, such as the

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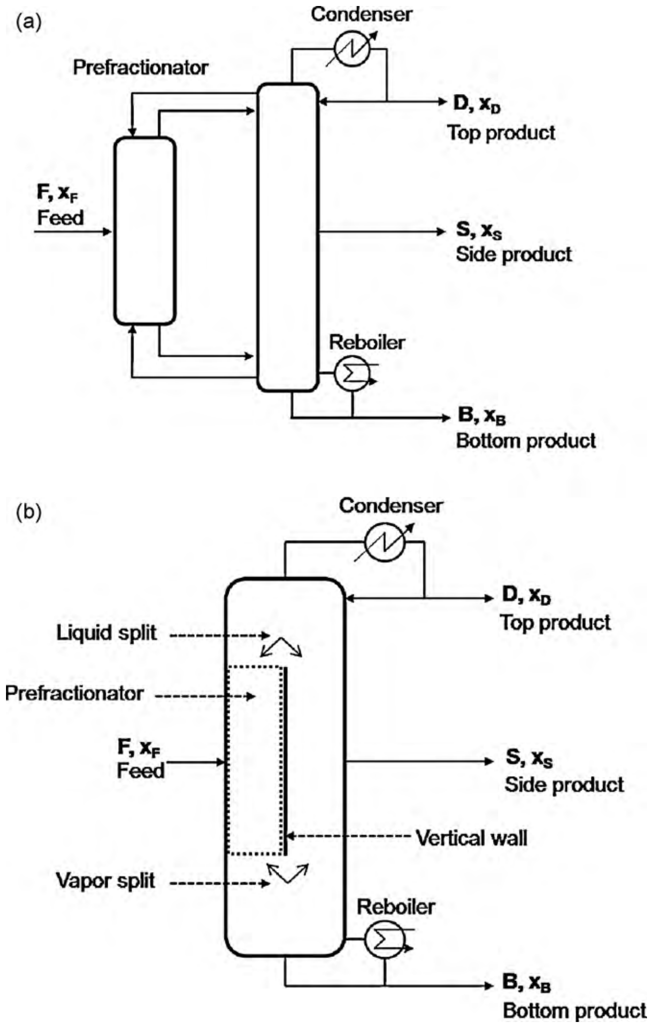

Fig. 1. Schematic diagram of: (a) Petlyuk column and (b) dividing wall column.

Petlyuk column and the prefractionator arrangement, has been proposed for retrofitting [14]. Likewise, addition of a new column, such as a post-fractionator or prefractionator, could also provide a process debottlenecking option [16]. Accordingly, construction material for the new column must be considered, which is related directly to investment cost and corrosion phenomenon. While some modification methods have been successfully proposed to reduce investment and operating costs, it is nevertheless necessary to consider each particular case based on realistic conditions.

The main objective of this work is to introduce how the DWC can be utilized for removing the bottleneck phenomenon as well as improving energy efficiency, particularly, in the acetic acid purification process comprising series of distillation columns when increasing the throughput. One of main ideas is to shift the increased load into the subsequent columns and to have the DWC take care the load. Various possible distillation arrangements as well as the DWC configuration were studied and evaluated to find the best option in a systematic manner.

The shortcut method utilizing a three conventional column configuration was used to find the initial DWC structure in a simple manner. The optimal design of the DWC was considered in terms of the total number of trays, feed tray location, and side tray location, as well as the dividing wall section. In addition, the internal recycle flow distribution around the dividing wall was investigated as the main optimizing variable. The study was performed using Aspen HYSYS V7.1. These results were then compared to the performance of the conventional column sequence and the Petlyuk column, as well as the prefractionator arrangement.

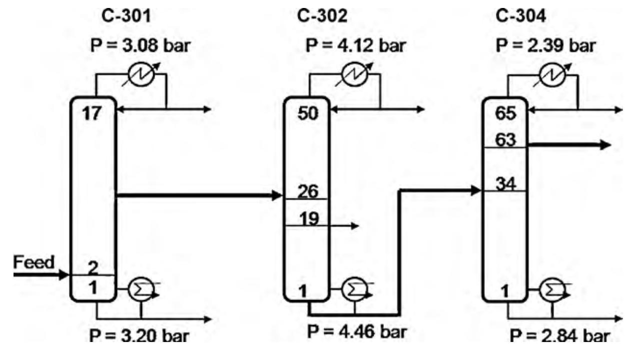

Fig. 2. Simplified flow sheet illustrating the existing separation train of three conventional columns.

1.1. Existing process configuration

Acetic acid (AA) is an important industrial commodity chemical, with many industrial uses and a world demand of nearly six million tonnes per year [17]. The preferred industrial method for its manufacture is carbonylation of methanol, accounting for approximately 60% of the total world manufacturing capacity, whereby a mixture of crude AA and contaminants is separated in a series of distillation columns [18]. Fig. 2 illustrates the existing distillation column sequence and current operating conditions. The existing system has three valve-trayed columns of 4.4, 3.0, and 3.8 m diameters, with 17, 50, and 65 trays, respectively. The production medium for the acetic acid in the purification stage at 130–200 °C contains up to 16% water, 26% methyl iodize, and other components such as methyl acetate, methanol, hydrogen iodide, formic acid (FA), and propionic acid (PA). The role of the C-301 fractionating column is removal of the light components and portions of water in the mixture, while treating both water and FA, and PA, are the purpose of the C-302 dehydration column and the C-304 refining column, respectively.

In the production of AA, the construction material has to be considered carefully because of corrosion. Usually, nickel–molybdenum alloys (Hastelloy B and Hastelloy B-2) are employed in this very aggressive media for production of synthetic acetic acid. However, equipment made of Hastelloy is subject to enhanced corrosion [19,20]. Electrochemical corrosion can occur in iodide-containing AA media, damaging the fractionation and dehydration columns [21]. It is thus expedient to use zirconium alloys [20]. In this design, the fractionating C-301 and dehydration C-302 are constructed of zirconium, while the refining C-304 is constructed of 316SS as almost all iodide ion is removed before entering this column.

The feed composition, temperature, and pressure are described in Table 1. The simulation work was performed using simulator Aspen HYSYS V7.1. The NRTL-HOC property method that uses the Hayden–O'Connell equation of state as the vapor phase model and NRTL for the liquid phase was used for the prediction of the vapor–liquid equilibrium (VLE) of these simulations. Dimerization affects VLE, vapor phase properties, such as enthalpy and density, and liquid phase properties, such as enthalpy. The Hayden–O'Connell equation reliably predicts the solvation of polar compounds and dimerization in the vapor phase that occurs with mixtures containing carboxylic acids [22]. Table 2 presents the conditions and product specifications for each column in the existing column sequences. From the base case simulation model, it shows that the energy consumption of three columns are 17.39, 13.05, and 19.06 Gcal/h, respectively.