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Control of fully heat-integrated pressure swing distillation for separating isobutyl alcohol and isobutyl acetate

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ABSTRACT

Design and control of fully heat-integrated pressure swing distillation for separating isobutyl alcohol and isobutyl acetate are explored. The steady state design and dynamic simulation are performed via Aspen Plus and Aspen Plus Dynamics, respectively. Some control structures for this process are put forward to hold the products purities. It is found that the control structure with pressure-compensated temperature control can effectively address feed flow rate and composition disturbances despite of small flaw. In order to address to this small flaw, the control structure with a cascade connection of pressure-compensated temperature and composition control is proposed and this control structure can precisely maintain the products purities.

1. Introduction

Isobutyl acetate (IBAC) is widely utilized as a significant solvent in some fields including leather, perfume and pharmaceutical industry. Traditionally, isobutyl alcohol (IBA) with acetic acid is employed to synthesize IBAC. The product after reaction contains the mixture of IBAC and IBA because of the limited conversion ratio. It is a pity that the complete separation of the mixture of IBAC and IBA cannot be achieved by simple distillation process due to the formation of minimum boiling azeotrope between them.

Plenty of separation methods can be employed to separate the azeotrope, including extractive distillation (ED), pressure swing distillation (PSD) and so on. ED can be used to separate the azeotrope when a suitable solvent is introduced, which can enhance the relative volatility between the azeotrope. The design and control of ED process are studied in lots of papers [1–5]. Some parameters affecting the control of ED process, such as the solvent [6] and solvent flow rate [7], are explored. Different from the conventional solvent, which is the heaviest matter compared with the azeotrope, intermediate solvent can be also applied in ED process [8].

PSD is an additionally feasible method for the separation of the azeotrope when azeotropic composition is quite sensitive to pressure. Lewis was the first person to suggest adopting PSD process to separate the azeotrope [9]. PSD process is extensively investigated in many articles [2,10–15]. Hamad and Dunn [10] used the global energy optimization strategies to decrease energy consumption of PSD process. Luyben [2] performed the design, optimization and control of PSD process for the separation of acetone/methanol. A special azeotrope, whose type changes with pressure, was separated using PSD by Wang et al. [15]. In addition, though one azeotrope is pressure-insensitive, new PSD with the introduction of an entrainer is still an advisable way to separate the azeotrope. Knapp and Doherty [16] proposed a new PSD process to separate pressure-intensive azeotrope with an entrainer, which can fulfill the formation of pressure sensitive distillation boundary. Design and control of new PSD to separate pressure-insensitive azeotrope phenol and cyclohexanone was performed by Li et al. [17].

Nowadays, it is of utmost importance to cut down the energy consumption for energy-intensive distillation process due to the rising energy prices. Since operation pressures of two columns in PSD process are different, it is possible to lower energy consumption via heat integration. There are two types of heat integration for PSD process [18]. One is the condenser/reboiler heat integration and the other is the rectifying/stripping section heat

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integration. In this paper, the condenser/reboiler heat integration is considered.

The fully heat-integrated PSD has been investigated in many articles because it can save energy to a certain extent compared with PSD with no heat integration. Luyben [19] explored the design and control of several type of heat-integrated PSD including fully, partially and no heat-integrated PSD. The results revealed that fully heat-integrated PSD needed lower energy consumption compared with no heat-integrated PSD, but controllability of fully heat-integrated PSD was worse than no heat-integrated PSD. Thus a tradeoff between dynamic performance and energy consumption needed to be considered. Yu et al. [20] used fully heat-integrated PSD for the separation of methylal/methanol and some control structures were put forward. They found that the improved pressure-compensated temperature control could well handle the feed flow rate and feed composition disturbances. Hosgor et al. [21] also studied the dynamic performance of the fully heat-integrated PSD process. The results showed that this process needed a pressure-compensated temperature control structure to solve the large disturbances in feed flow rate and composition well.

Simulation and optimization of separation of IBAC and IBA by extractive distillation with a solvent of *n*-butyl propionate and PSD were performed using Aspen HYSYS in the article [22]. The results illustrated that PSD was more suitable compared with the extractive distillation on the basis of total annual costs. However, the fully heat-integrated PSD is not considered, not mention to the control of this process.

This paper can be treated as an extended work for the separation of IBAC and IBA. In this paper, fully heat-integrated is adopted in order to reduce energy consumption, and control of this process must be studied due to the strong interaction between the two columns. Based on the steady-state results of flowsheet in the article, design of fully heat-integrated PSD process for separation of IBAC and IBA is performed. Furthermore, some control structures for this process are put forward and assessed by the feed flow rate and feed composition disturbances.

2. Steady-state simulation

In the flowsheet of the article [22], the fresh feed stream is mixed with the recycle stream as final feed to the high-pressure column (HPC) despite of the different composition of the feed stream and recycle stream. The mixture between the fresh feed stream and recycle stream results in back mixing and thus increases energy consumption. Partial optimization is implemented for this reason. Reboiler duty in the HPC is selected as a reference variable. The minimum of reboiler duty is acquired by changing the feed positions of the fresh feed stream and recycle stream. By adopting "Sensitivity" tool, the optimal feed position of the feed stream and recycle stream is stage 18 and 8, respectively.

Based on the total tray numbers and feed locations in each column in the flowsheet mentioned above, similar method to design fully heat-integrated PSD in the paper is adopted here. The final flowsheet of fully heat-integrated PSD is shown in Fig. 1. Compared with the total reboiler duty of 4.594 GJ/h in the conventional PSD in the article [22], the total reboiler duty, 3.630 GJ/h, is reduced by about 21% by using heat-integrated PSD in this paper. The temperature profiles in the HPC and LPC are depicted in Fig. 2.

3. Dynamic simulation

3.1. Basic control structure CS1

Plumbing system and equipment sizes have to be set in the steady-state simulation. According to the common heuristic [4], column bases and reflux drums must provide 5 min of liquid holdup when they are half full. Pressure drops of the control valves are specified as 3 bar with half open of the valves. Then pressure of the steady-state flowsheet is checked and pressure-driven dynamic simulation file is exported for the dynamic simulation.

The heat transfer rate of the condenser/reboiler is determined by the overall heat-transfer coefficient, the heat-transfer area and

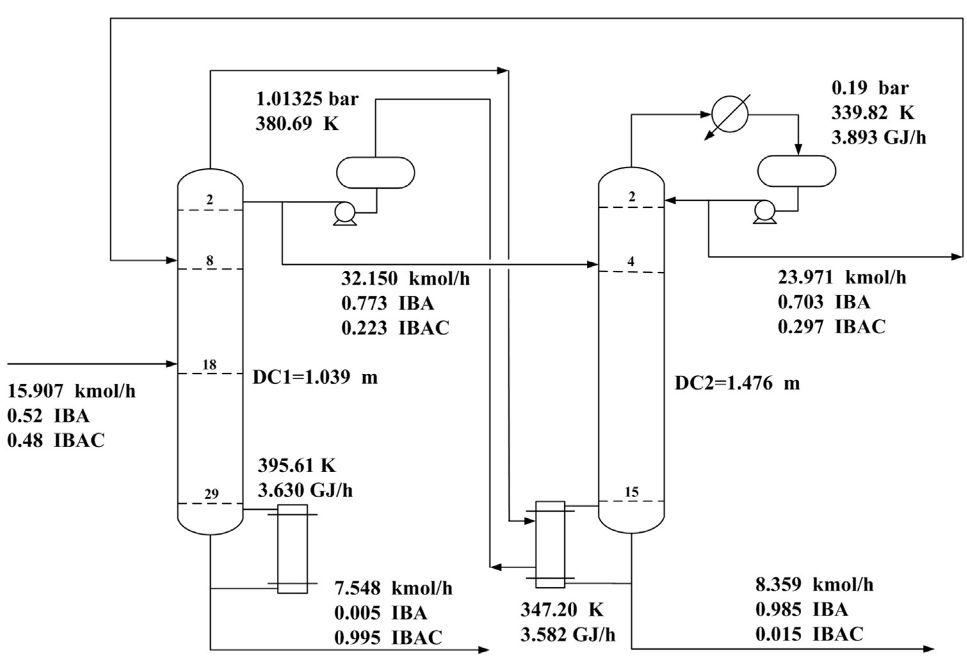

Fig. 1. The flowsheet of fully heat-integrated PSD process.