변형 구조의 삼성분 증류 시스템

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An Alternate Structure of Ternary Distillation System

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1. Introduction

When a distillation column for multi-component system is at total reflux operation, its distillation line is approximated to one of residue curves. At the total reflux operation, thermodynamic efficiency of the column is ideal to have minimum energy requirement. This ideal distillation line is also found from the profile of tray liquid composition of a fully thermally coupled distillation column (FTCDC) known to be one of energy efficient distillation systems.

Though the FTCDC consumes less energy than a conventional distillation system in most cases, its operation is difficult to hinder wide application of the column. In order to solve the operation problem many studies have been conducted in the search of a good operational strategy of the column. As an alternative structure for easy operation, modified arrangements of connecting streams in the column are introduced and analyzed. Also, the main column is divided into two separate columns while the two are thermally coupled for the easy manipulation of product specification, and the multivariable controllability is examined the improvement [1].

When a three-column distillation system described in Figure 1 has the liquid composition profile similar to one of the residue curves like the FTCDC, the high thermodynamic efficiency is maintained to lower the energy demand for a given separation. For the separation of a ternary mixture two distillation columns are utilized conventionally, but its profile of tray liquid composition is quite different from the residue curves. In other words, the column efficiency is far from the ideal. Adding a prefractionation column to the two binary distillation columns makes the composition profile similar to the FTCDC to result in high thermodynamic efficiency. While the additional column raises the number of control loops in the operation of the three-column system, the specification control of three products is much easier than that of the FTCDC due to the elimination of coupling among product compositions and column operation variables.

In this study, a modified distillation system for ternary mixture is proposed for high column efficiency and improved operability. The system is composed of three binary columns having a similar liquid composition profile to that of the energy-efficient FTCDC and binary column operability. The performance of the proposed system is investigated by applying it to the practical processes, and the utilization limitation of the system is examined. A HYSYS simulation is conducted for the performance evaluation.

2. Structural Design

The design of a distillation column begins with either operational variables, such as liquid and vapor flow rates, or structural information. In this study, the structural design information is obtained first because the information can be adopted from the design outcome of the FTCDC and the commercial design program, HYSYS, utilized in the design requires the information at the beginning of project formulation. The tray numbers of the prefractionator and the upper and lower sections of the

main column of the FTCDC are employed as the tray numbers of the prefractionation and the upper and lower columns of the 3-column system. Because the proposed system is designed to have a similar profile of tray liquid composition to the FTCDC, the design outcome of the FTCDC is utilized in the structural design of the system. For the design of the FTCDC, a structural design technique is employed and its detail is explained in Lee et al. [2].

The structural design of the FTCDC is based on the minimum tray column design. The highest column efficiency is obtained at total reflux operation, in which the minimum tray is required and the distillation line is similar to one of residue curves. Because mixing at feed tray lowers the efficiency, it is assumed that the composition of feed tray is equal to feed composition. Now two residue curves—one includes feed composition, and the other does the composition of side draw—are selected for the distillation lines of the prefractionator and main column. The numbers of trays are yielded from the stage-to-stage computation of tray liquid composition beginning with the feed composition for the prefractionator and the side draw composition for the main column. The location of feed and side draw trays is readily found from the computation. The location of interlinking trays is determined from matching the tray compositions of the prefractionator and main column. This is the structural information of the ideal minimum tray column. For a practical column, the tray numbers are taken twice the minimum while the proportion of feed, side draw and interlinking locations is maintained for the high tray efficiency. Once the structural information is determined, the operational variables, such as liquid and vapor flow rates, for a given set of product specifications are found from the iterative procedure of the HYSYS simulation.

3. Process Description

Two practical processes are utilized in this study. One is the fractionation process, which separates benzene, toluene and xylene from naphtha reformate. The other is the gas concentration process producing enriched ethane, propane and butane from gaseous mixture product in crude distillation, naphtha reformation and naphtha cracking processes. These processes handle large amount of products with significant energy consumption, and therefore it is useful to examine the reduction effect of utility requirement.

4. Results and Discussion

Though an FTCDC has high thermodynamic efficiency to reduce energy requirement comparing with the conventional 2-column system, its operational difficulty obstructs practical application of the FTCDC. In order to improve its operability a 3-column distillation system is introduced here and its performance of energy requirement reduction is examined by comparing utility consumption among the 3-column system, the FTCDC and the conventional 2-column system. Because the composition profiles of tray liquid of the 3-column system and the FTCDC are similar, their distillation column efficiency is expected to be higher than that of a conventional 2-column system.

For BTX process the structural design of the 3-column system is derived from the structural design results of the FTCDC (Lee et al., 2004) as listed in Table 3. Though minor modification is accompanied, the structures of the two systems are similar. The upper column of the 3-column system is analogous to the upper section of the main column of the FTCDC, and so is the lower column to the lower section. Two prefractionators of the systems are also close.

The composition profile of tray liquid of the 3-column system is shown in Figure 2, where circles are for the prefractionator, plus symbols are for upper column and times symbols are for lower column. The circles denoted U and L are the compositions of feeds to the upper and lower columns, respectively. Note that the concentrations of main feed described with an F, feeds of U and L are collinear. In case of the FTCDC the profile is illustrated in Figure 3, where L2 is the composition of liquid from the main column to the prefractionator and LB is that from the bottom of the prefractionator. The three compositions are arbitrary in this system unlike the 3-column system, and the flexibility of the composition distribution of connecting streams makes the structural design of the

FTCDC adjustable. For the conventional 2-column system, the profile shown in Figure 4 is quite different from the previous two and is far from residue curves.

Though the three different systems produce the same products of a given set of composition specifications, utility consumption varies in the three. The proposed 3-column system and the FTCDC requires 12% and 13% less energy than the conventional 2-column system, respectively. This indicates that the thermodynamic efficiency of the former two systems is higher than the last system. It is explained with the composition profile of tray liquid. Whereas the former two have profiles (Figures 2 and 3) similar to residue curves, the 2-column system has quite different curves (Figure 4). The high efficiency and low energy requirement of the FTCDC are known to field engineers, but its operational difficulty induced reluctance on the practical application of the column. The 3-column system solves the operational problem associated with the FTCDC while the high column efficiency is maintained. Though one more column than the conventional 2-column system is employed in the 3-column system requiring more control loops, the specification control of three products is much easier than that of the FTCDC.

For gas concentration process, again the profiles of the 3-column system and FTCDC are similar. However, the comparison of utility consumption among the three systems is quite different from that of the BTX process. The design results of the gas concentration process are summarized, which shows that the FTCDC requires 18% less utility than the conventional 2-column system while the 3-column system needs 3% more. The answer of the high energy requirement of the 3-column system is found from the composition profile. Unlike the FTCDC, the compositions of feed and two products of the prefractionator in the 3-column system have to be collinear. This requirement generates unnecessary separation to result in more energy demand. The outcome of the 3-column system for the gas concentration process indicates that the system can not be utilized in any system to improve the operability while maintaining high column efficiency.

5. Conclusion

A modified structure of a fully thermally coupled distillation system is examined for possible improvement of operability. The system is composed of three binary columns for the easy control of product specifications. A brief procedure of structural design and operational variable computation is explained, and the performance of the system is investigated with two practical processes, BTX and gas concentration processes. The investigation results show that the 3-column system is useful for the BTX process but it is not for the gas concentration process. Unlike the FTCDC the prefractionator of the 3-column system requires the compositions of feed and two products to be collinear, which demands extra separation to raise energy requirement in some cases.

Acknowledgment

References

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[2] Ju Yeong Lee, Y.H. Kim, Kyu Suk Hwang, Application of a Fully Thermally Coupled Distillation Column for Fractionation Process in Naphtha Reforming Plant, Chem. Eng. Processing, 43(2004), 495-501.
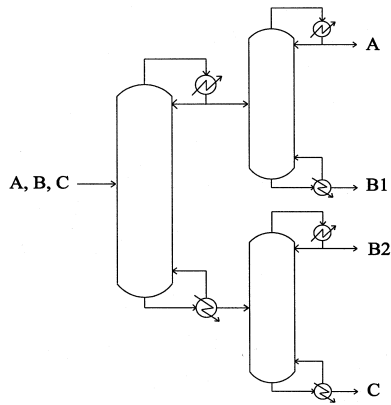
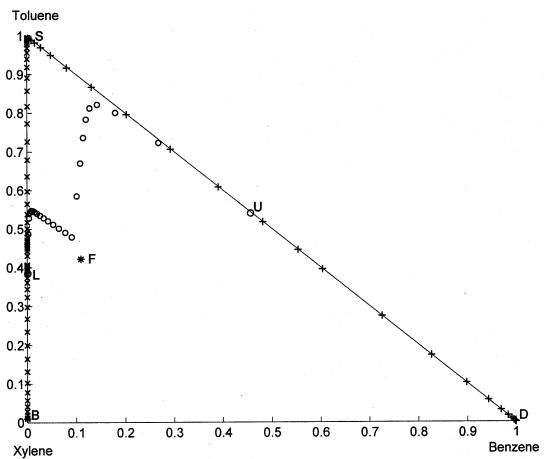Figure 1. Schematic of a 3-column system.

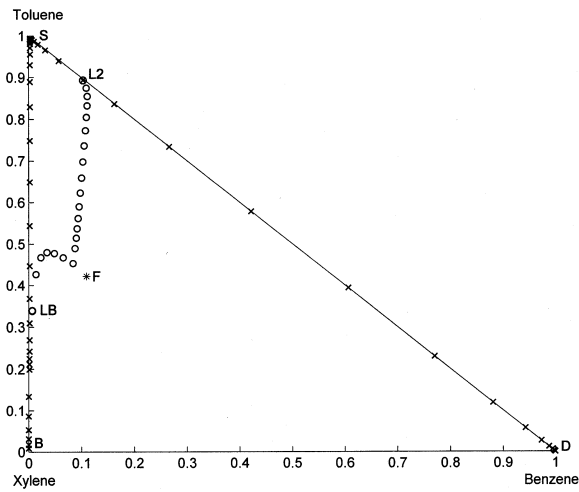Figure 2. Liquid composition profile of BTX process in 3-column system.

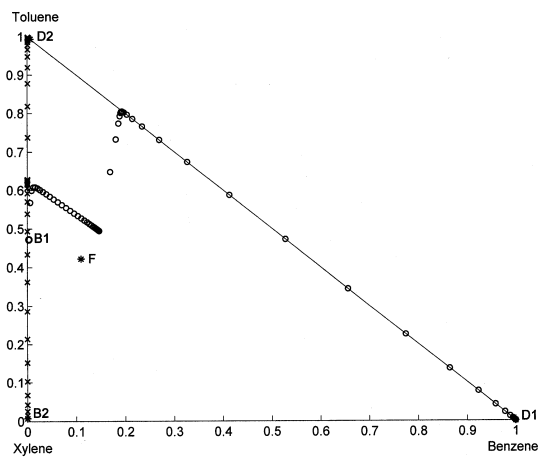Figure 3. Liquid composition profile of BTX process in FTCDC system.

Figure 4. Liquid composition profile of BTX process in conventional 2-column system.