변형 열복합 증류탑의 설계와 제어

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Design and Control of a Modified Fully Thermally Coupled Distillation Column

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Introduction

Because a fully thermally coupled distillation column (FTCDC)—consists of a prefractionator and a main column interlinked with two-way transfers—produces three products in a column, the specification control of the products is more complex than that of conventional binary distillation columns. Generally the raised reflux flow and vapor boilup elevate the specification, but the effect of the increase is limited in the case of the FTCDC control.

There have been two groups of studies to improve the operability of the FTCDC. One is devising new column structure for better controllability of the column. Agrawal and Fidkowski [1] proposed more operable arrangements of distillation sections in the FTCDC for easy vapor transfer, and later they introduced modified structures of the FTCDC by eliminating one of two-way transfers between the prefractionator and main column for easy operation of the system. Wolff and Skogestad [2] examined various control structures of the FTCDC to find an optimum control scheme. A configuration of partially separated main columns has been proposed to improve the operability by Kim [3].

In this study, a new control structure of the modified FTCDC has been proposed, and its performance is examined in the regulation and set-point tracking of the specification of three products. In the selection of the manipulated variables, the step response of the column is utilized to analyze the dynamic behavior of the column. The step changes of feed flow rate and feed composition are applied for the investigation of regulation performance, and those of the set points of product specification are for the set-point tracking.

Distillation Column Design

The divided wall column (DWC) demonstrated in Figure 1c is one of the fully thermally coupled distillation columns (FTCDC), and it has been successfully operated at the commercial plants in many countries. Due to its wide application in many plants, the field engineers prefer to adopt the column for their new projects. However, the structure has some limitations. The utilization of the existing columns is not possible, and the middle section with divided wall has to use structured packing, which limits the size of the column. Further more, the manipulation of vapor distribution between the prefractionator and main column is not available.

Instead of the divided middle section of the DWC, two separated columns can be used as in the Petlyuk column. In this configuration either tray or packed column can be utilized, and therefore the two binary columns of the conventional distillation system are placed as the columns, C1 and C2, in Figure 1d. In the FTCDC, the upper and lower sections of the main column have to handle the combined vapor flow of two binary columns in the conventional system, larger diameter columns, E1 and E2, are necessary. These columns are newly installed, but the tray numbers are small. By setting the pressure of the column E2 the highest and that of E1 the lowest no compressor is necessary for vapor flow. Instead two pumps, much better than the compressor in terms of cost and operation, are used for the liquid flow.

Many distillation systems process different composition and flow rates of feed. The operation of the DWC handles the split of liquid flows between the prefractionator and main column, the vapor split between them is not adjustable, which limits the column operation for the different feed composition and flow rates. Both the liquid and vapor splits between the prefractionator and main column are adjusted in the proposed distillation system here. This expands the operation range of the distillation system. Though a large change of feed condition is not handled, its minor change can be easily adapted with the manipulation of the splits. The design of the distillation system for a BTX separation begins with the conventional system in direct sequence as described Lee, et al.. The conventional system utilizes two distillation columns as described in Figure 1(a). The first produces benzene as overhead product, and the next separates toluene and xylene mixture. Table 1 lists the specifications of feed and products. From the conventional system design, the numbers of stages for the columns C1 and C2 in Figure 1(d) are determined. Here the tray efficiency of 75 % was considered.

The commercial design software HYSYS was used in this study. When the numbers of trays and column pressure are given in the design with the HYSYS, the operating condition is iteratively calculated for the desired specification of the products. In this study the numbers of trays for the columns E1 and E2 were determined to require the minimum reboiler duty. For the easy vapor flow from the lower main column to the upper main column through the prefractionator and middle main column, the pressure in the lower main column was set the highest and that in the upper main column was the lowest as indicated in Table 2. On the other hand, the liquid flows against the pressure distribution among the columns. It flows from the lowest pressure to the highest, and therefore two pumps are necessary among the columns as depicted in Figure 1(d). Note that the installation and operation of a pump are not big problem.

After the structural design of the proposed system is completed, the operational variables of the proposed FTCDC can be found from process simulation. The information of tray numbers and column pressure are all needed to begin the computation.

Results and Discussion

For the formulation of control structure of the proposed distillation system, a dynamic simulation was conducted based on the steady-state design result summarized in Table 2. Figure 2 shows the process diagram for the dynamic simulation of the proposed process using the HYSYS. In the examination of dynamic behavior of the proposed FTCDC, the 14 components in feed are separated in three groups, and the compositions of benzene, toluene and m-xylene have been tracked as key components in the light, intermediate and heavy products, respectively.

In order to devise a control structure for the control of the key components in three products, three possible manipulated variables are selected. Two variables of reflux flow and vapor boilup rates are widely used manipulated variables in the distillation column control. The third variable can be selected from various other operational variables, but the vapor flow rate in the prefractionator was used for the specification control of side product. In the control of product specification, the sensitivity and response time of an operating variable to the control of a controlled variable are the most important factors in the pairing of the control structure. In that consideration, the reflux flow for the overhead product and the vapor boilup rate for the bottom product are obvious pairing in the distillation column control. Because the side product is not an end product like the overhead or bottom product, the control of the side product is difficult. In other words, no operating variable easily manipulated and close to the location of the product draw. Therefore, there is no candidate for the fast response with high sensitivity variable for the control. Two closest variables are liquid and vapor flow rates in the middle main column, and the vapor flow rate is utilized in this study. Note that the response from the rate change in vapor flow is much faster than that of the liquid flow.

The control performance of set-point change in the three product specification is demonstrated in Figure 3. The three plots in a row are the step changes of set point in the product specification for the overhead, side and bottom, respectively. The dashed lines are the set points. The top and bottom figures for the overhead and bottom products are fine for the control of the product specification as expected. The change of side product specification gives fluctuated response in the side product specification, though it is controllable.

From the performance evaluations in the set-point tracking and regulation, the proposed pairing of the reflux flow, prefractionator and vapor boilup rate and the three products of overhead, side and bottom product, respectively, gives satisfactory results of control.

References

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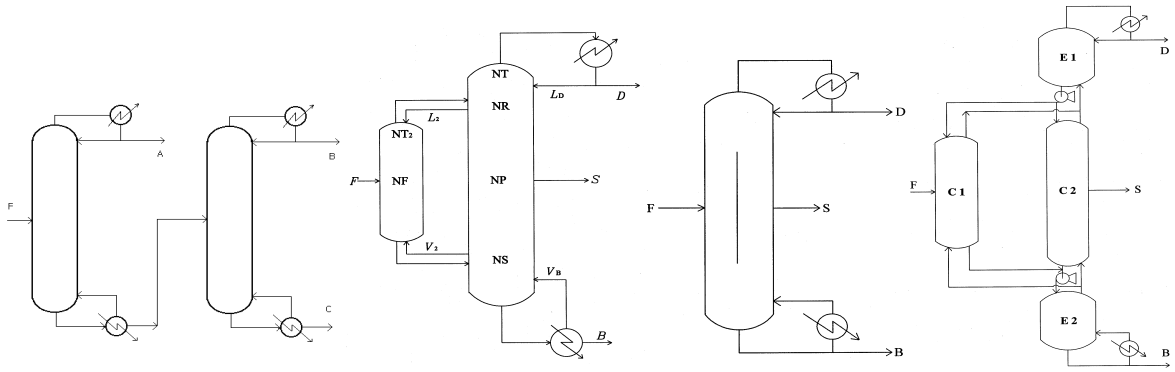
2. E. A. Wolff and S. Skogestad, *Ind. Eng. Chem. Res.*, **34** (1995).
3. Y. H. Kim, *J. Chem. Eng., Japan*, **36**, 1503 (2003).

Table 1. Specifications of feed and products (kmol/h)

Component	Feed	Product	Overhead	Side Bottom
(Light)				
n-Hexane	0.2639	0.2638	0.0000	0.0000
n-Heptane	0.0226	0.0225	0.0003	0.0000
n-Octane	0.2005	0.0000	0.1866	0.0002
n-Nonane	0.4206	0.0000	0.0010	0.4204
Benzene	222.44	221.73	0.0501	0.0000
(Intermediate)				
Toluene	508.72	0.0148	508.92	0.0011
(Heavy)				
p-Xylene	117.89	0.0000	0.1925	117.86
m-Xylene	257.15	0.0000	0.3614	257.03
o-Xylene	112.56	0.0000	0.0235	112.39
E-Benzene	11.663	0.0000	0.0849	11.860
n-PBenzene	0.3798	0.0000	0.0000	0.3797
1M2-EBenzene	23.240	0.0000	0.0000	23.235
123-MBenzene	261.23	0.0000	0.0000	261.18
1234-M-BZ	57.841	0.0000	0.0000	57.838
Total	1574.0	222.0	509.8	842.20

Table 2. Design results of the proposed distillation system

Name	Prefract	Proposed column Up_ main	Mid_ main	Low_ main
Structural				
number of tray	45	15	38	35
feed/side product	25		19	
Operating				
Pressure(kg/cm^2)	1.05	0.53	1.05	1.56
Feed(kmol/h)	1574			
Overhead(kmol/h)		222.0		
Bottom(kmol/h)				842.2
Side(kmol/h)			509.8	
Reflux(kmol/h)	452.5	2188	1433	2921
Vapor boilup(kmol/h)	841.9	2108	1237	2149
Heat duty(GJ/h)				70.90



(a) (b) (c) (d)

Figure 1. Various structures of distillation system for ternary separation. (a) conventional direct sequence, (b) Petlyuk column, (c) divided wall column, (d) modified Petlyuk column.

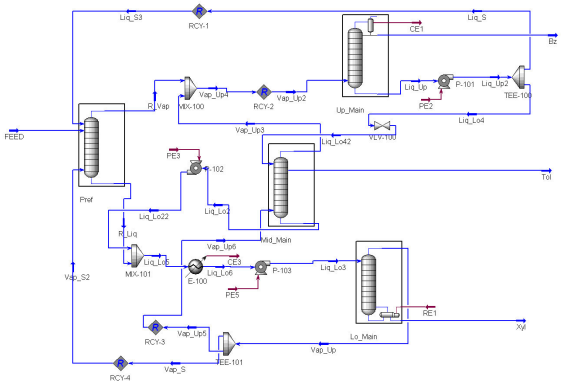


Figure 2. A process flow diagram of the proposed process.

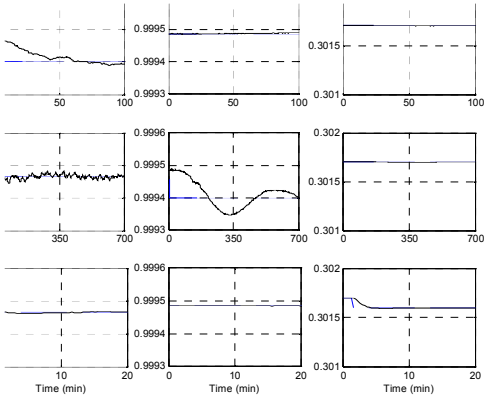


Figure 3. Responses of step set-point changes in overhead, side and bottom products.