운전성 개선을 위한 열복합 증류탑의 변형

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Modification of a Fully Thermally Coupled Distillation System for Operability Improvement

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Introduction

One of disadvantages in the utilization of a fully thermally coupled distillation column (FTCDC) over conventional two-column system is the difficulty of the setting of column pressure. Whereas the pressures of the two-column system can be separately determined, the FTCDC does not allow the independent manipulation due to two-way connection between a prefractionator and main column. This causes even more difficult situation with a divided wall column. In conjunction with the pressure adjustment, the manipulation of vapor flow is not simple in the FTCDC, and a divided wall column is often implemented in field applications to eliminate the problem. Yet the flow control is a cumbersome task for either structure of the systems. Agrawal and Fidkowski arranged the sections of the prefractionator and main column of the FTCDC by pressure drop to make vapor flow easy.

In addition, the specification control of three products in the FTCDC is a major obstacle for extensive application of the system. Separated main columns were examined by Kim for the improvement of operability. The columns are separately operated except that the reboiler of the upper column and the condenser of the lower are combined to be a single heat exchanger for the heat integration to reduce energy requirement.

In this study a new structure of the FTCDC is introduced to handle the pressure difference, easy vapor flow and operability improvement as well. The system has two separated main columns. The procedure of column design is explained and the performance of the proposed system is investigated through simulation study using the HYSYS.

Design procedure

Because the proposed system is a modification of an FTCDC, the column design begins with the design of the FTCDC and a structural design procedure is applied here. The structural design is based on a minimum tray column design. The residue curves enclosing feed composition or the composition of side draw are selected for the distillation lines of the prefractionator and main column of the FTCDC. An equilibrium stage-to-stage computation of tray liquid compositions beginning with the feed composition for the prefractionator and the side draw composition for the main column gives the numbers of tray of the prefractionator and main column. The locations of feed and side draw trays are also found from the computation result by counting tray numbers. The interlinking trays between the prefractionator and main column are determined to result in the least difference of tray compositions of two interlinked trays. Because this is the structural information of an ideal minimum tray column, the tray numbers are taken twice the minimum for a practical column. In the computation the proportion among feed, side draw and interlinking locations is maintained for the high thermodynamic efficiency of the column. 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 HYSYS simulations.

The proposed system of separated main columns illustrated in Figure 1 requires the tray number of the separation, which is the location of side product as an obvious selection. By setting the stage of the product at the bottom of the upper main column, the specification control of the side product is easier than placing the location in the middle of the column. Rest of the structural information of the proposed system is readily found from the structural design of the original FTCDC.

In order to have products of a given specification, one needs a proper set of operation condition for the distillation system of which the structure is found from the above. The condition is obtained from a trial simulation until the computed product composition meets the specification. Because the commercial process design program HYSYS is utilized here, the trial computation with the known distillation structure is relatively simple procedure. In the formulation of the HYSYS simulation, column pressure is required to be supplied. The pressure of the lower main column is set at highest, that of the prefractionator is the next, and that of the upper main column is lowest for easy vapor flow. Instead, liquid flow in reverse direction to the vapor flow demands a pump to overcome pressure difference. This arrangement of pressure eliminates a compressor for the vapor flow, which is expensive and difficult to maintain. The variables of column operation are adjusted during the simulation until a predetermined product specification is found. The simulation result is listed in Table 1 along with the structural information.

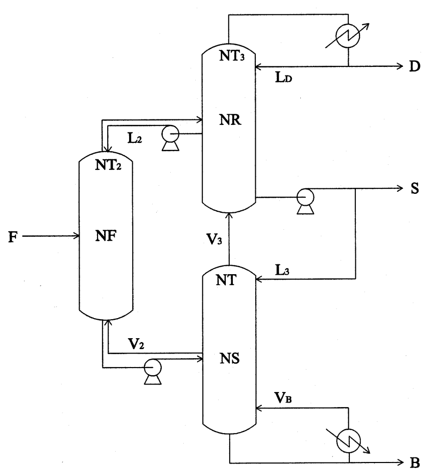

Figure 1. A schematic diagram of a modified fully thermally coupled distillation column.

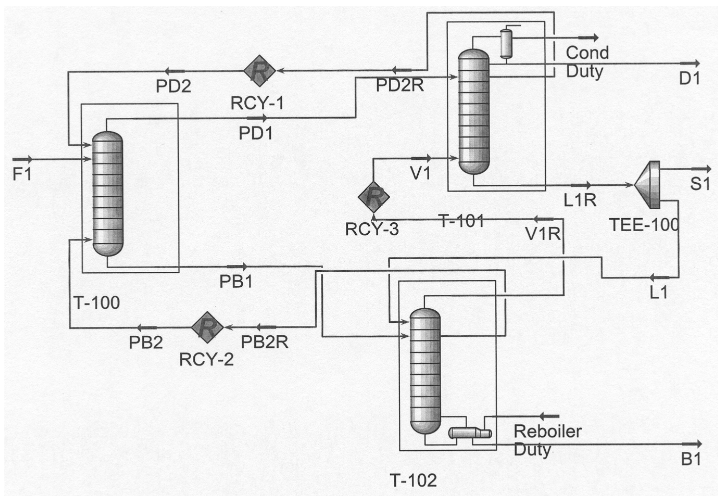

Figure 2. A process flow diagram of a modified fully thermally coupled distillation column in HYSYS simulation.

Table 1. Tray numbers from structural design and operating conditions in fractionation process.

Name	Proposed FTCDC			Original FTCDC	
	Prefract.	Upper	Lower	Prefract.	Main
Structural					
number of tray	21	62	27	21	89
feed/side product	15	16	22	15	62
interlinking srages					16, 84
Operating					
feed (kmol/h)	801.8	513.1	1071	801.8	
overhead (kmol/h)		86.86			86.85
bottom (kmol/h)		337.8	377.4		377.4
side (kmol/h)		289.9	492.8		337.8
reflux (kmol/h)	289.9	1836	1052	290.1	1792
vapor boilup (kmol/h)	492.8	1254	1676	492.9	1634
heat duty (GJ/h)			60.78		59.35

Example process

A practical process is utilized for the performance evaluation of the proposed system of this study. A BTX fractionation process, which separates benzene, toluene and xylene from naphtha reformate. The process handles a large amount of products with significant energy consumption, and therefore the impact of utility reduction obtained from utilizing an energy efficient distillation system is not negligible. The flow rates of feed and products of the process in a typical plant are listed in Table 1.

Results and discussion

A HYSYS process flow diagram of the proposed system is described in Figure 2. The proposed 3-column process has higher column pressure than the original FTCDC to result in a slight increase of utility requirement. For the production of same specification products, the proposed system requires 2.4% more heat duty than the original FTCDC.

The operability improvement of an FTCDC was investigated by rearranging the sections of the prefractionator and main column. The rearrangement was focused on the easy vapor flow between the two columns considering column pressure. Because independent manipulation of column pressure is unavailable in the system, a sufficient pressure difference to make the vapor flow easy is not provided. A partial separation of main column connecting the upper and lower sections only with a heat exchanger was introduced and examined the operational difficulty with multi-variable controllability indices. In the system the upper and lower sections of the main column are thermally connected for energy saving, whereas no material transfers between them. The manipulation of product composition in the separated column is easier than the single combined column.

A combination of these two improvements is devised leading to this study of separated main column structure. Because the columns are independently operated, their pressures are readily manipulated for the easy flow of vapor between interlinked columns, which is not available in the previously studied configurations. Also, a complete separation of the main column improves the operability of the system compared with the original FTCDC or partially separated system. For the examination of the operability improvement, responses of product composition with step changes of reflux and vapor boilup rates and side draw rate are scrutinized. The composition variations of three products with step change of reflux flow rate are illustrated in the top three figures of Figure 3. While liquid flow rate of the lower main column is unchanged, the reflux flow rate at the upper main column decreases resulting the purity reduction of overhead product with maintained compositions of side draw and bottom product. Though the manipulation of liquid flow rate at the lower main column requires an intermediate reservoir at the liquid flow stream between the upper and lower main columns for the adjustment of the liquid flow, separate control of liquid flows at the columns is available, which is not with the original FTCDC. As shown in the top three plots of Figure 4 the composition responses of three products are coupled with the step change of reflux flow making separate control of the compositions difficult. The step responses of vapor boilup and side draw rate changes indicate similar performance with the original and proposed configurations. Because the manipulation of reflux flow can control the composition of overhead product in the proposed column, the control of three product specifications is easier than that in the original FTCDC.

Conclusions

A new configuration of a fully thermally coupled distillation system having sections of different pressures is proposed, and its design and performance are examined. The system has two separate main columns, and three sections of a prefractionator and two main columns are interlinked with vapor and liquid transfers.

The pressures of three sections of the proposed distillation system can be set for easy vapor flow between the sections without a compressor of large investment and difficult operation. In addition, it is possible to independently adjust the operation pressure according to product volatility whereas the section pressure of the original FTCDC is not determined independently. Finally the responses of step change of reflux, vapor boilup and side draw rates indicate that the proposed configuration gives better operability than the original FTCDC due to separate manipulation of liquid flow in the upper and lower main columns.

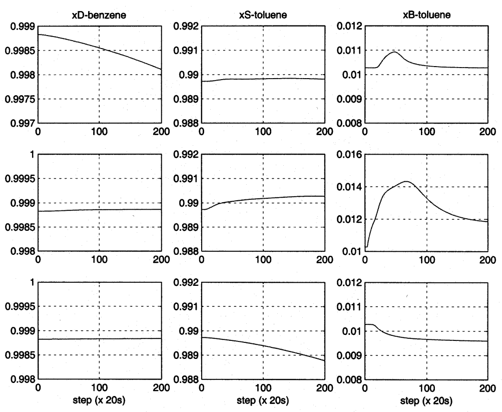

Figure 3. The responses of overhead, side draw and bottom product specifications with step changes of reflux, vapor boilup and side draw rates in a modified FTCDC for BTX fractionation process. Top are of reflux flow rate, middle are of vapor boilup rate and bottom are of side draw rate.

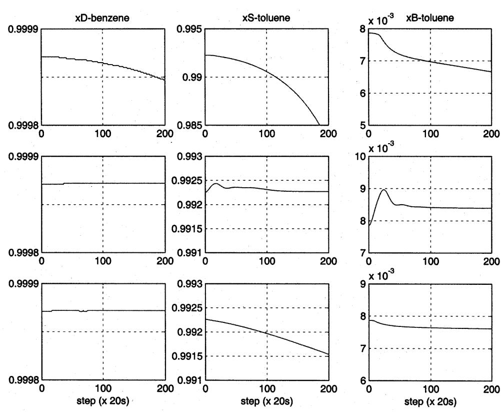

Figure 4. The responses of overhead, side draw and bottom product specifications with step changes of reflux, vapor boilup and side draw rates in an FTCDC for BTX fractionation process. Top are of reflux flow rate, middle are of vapor boilup rate and bottom are of side draw rate.