Korean J. Chem. Eng., **18**(4), 428-431 (2001)

Operating Strategies and Optimum Feed Tray Locations of the Fractionation Unit of BTX Plants for Energy Conservation

Jae-Cheon Lee, Yeong-Koo Yeo*, Kwang Ho Song and In-Won Kim†**

Dept. of Chemical Engineering, Konkuk University, Seoul 143-701, Korea
*Dept. of Chemical Engineering, Hanyang University, Seoul 133-791, Korea
**LG Chemical Ltd., Research Park, Daejeon 305-380, Korea
(*Received 17 April 2001 • accepted 22 June 2001*)

Abstract−Operating strategies and optimum feed tray locations were studied in a typical fractionation process of a BTX plant in Korea in order to reduce energy consumption. Control systems with fixed V/F or R/F ratios could be recommended for various feed compositions. By choosing the optimum feed tray location for the columns, about 16% of energy consumption could be reduced.

Key words: Distillation, Process Control, Optimum Feed Tray, Energy Conservation

INTRODUCTION

Since distillation columns are major energy-intensive units in chemical plants, the recent increases in fuel cost have stimulated plant engineers to find better operating strategies, better control systems and optimum feed tray locations of distillation columns [Zaki and Yoon, 1989; Nada et al., 2000; Seo et al., 2001; Kim, 2000]. The old operating strategies and feed tray locations should be re-evaluated in order to reduce energy operating costs in existing plants.

Luyben [1975] compared three alternative operating strategies (or control systems) from a steady-state energy consumption standpoint: constant-product-composition operation (or dual composition control), constant-heat-input operation (or control with fixed vapor boilup-to-feed rate (V/F) ratio), and constant reflux operation (or control with fixed reflux-to-feed rate (R/F) ratio). Luyben noted that no conclusions could be drawn as to what is the best control system from an energy conservation standpoint for all distillation columns. It was recommended that these V/F ratios be calculated for each particular column. He also found that the reduction of energy consumption by using the optimum feed tray for each feed composition, as opposed to some fixed locations, could be quite different.

In this paper, operating strategies (control systems) and optimum feed tray locations were studied in a typical fractionation process of the BTX plant in Korea in order to reduce energy consumption.

STEADY-STATE SIMULATION OF THE FRACTIONATION UNITS

The BTX plant is composed of four unit processes (hydrotreating, extraction, fractionation and hydrodealkylation). The products from extraction units are fed to fractionation units, and high purity benzene, toluene, mixed xylene are produced from fractionation columns. The fractionation units at BTX plants are one of the very complex and the most energy-consuming process.

The fractionation unit consists of a benzene column, a toluene column, a xylene column, and a solvent column. This paper focuses on the first three columns, which produce high purity products: 99.9% of benzene, 99.5% of toluene, and 90% of mixed xylene. The conceptual design data and operating pressure ranges of each column are shown in Table 1. The process flow diagram of the fractionation unit studied in this paper is shown in Fig. 1. The products of toluene and xylene are drawn at the top of the columns, but benzene is drawn from the fifth tray to prevent the light ends involved.

Table 1. Conceptual design data for a typical fractionation unit

	Benzene column	Toluene column	Xylene column
Number of tray	75	70	47
Feed tray	48	41, 48	26, 30
Pressure (kg/cm^2-g)	0.03-0.45	3.42-3.92	0.35-0.45

In order to simulate the fractionation process, a process simulator, HYSYS, was used with the real operating data of a typical fractionation unit of the BTX plant in Korea [Hyprotech, 1998; Tolliver, 1978]. Fig. 2 shows that the predicted temperature profiles follow the real measured profiles of the columns. Thus, this steady-steady model was used to calculate the V/F and R/F ratios of the columns for finding the best operating strategies and optimum feed locations in the next section.

SELECTION OF OPERATING STRATEGIES

Three different operating strategies (or control systems) were studied to find a better operating strategy for the columns. The proper choice of control strategy could save energy consumption in the distillation processes.

1. Dual Composition Control System

A dual composition control (DCC) system is used to simultaneously control both top and bottom product compositions, X_D and X_B. Fig. 3 illustrates a typical DCC system. For a given feed composition, X_F, the vapor boilup V and reflux R of the toluene column were calculated by using the model used in the previous section. For example, the V/F and R/F ratios in the toluene column are shown

†To whom correspondence should be addressed.
E-mail: inwon@konkuk.ac.kr

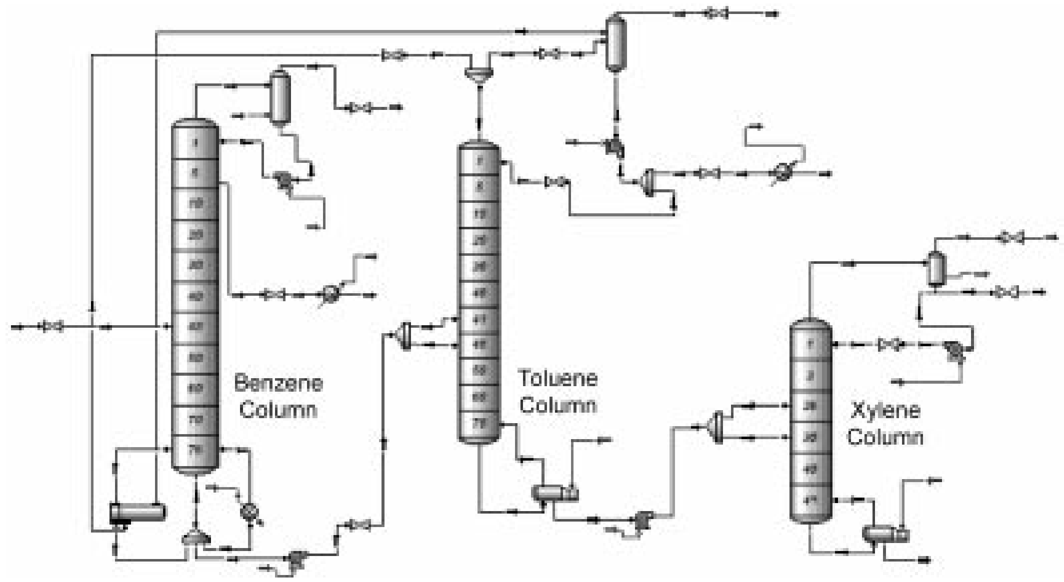

Fig. 1. The process flow diagram of a typical fractionation unit.

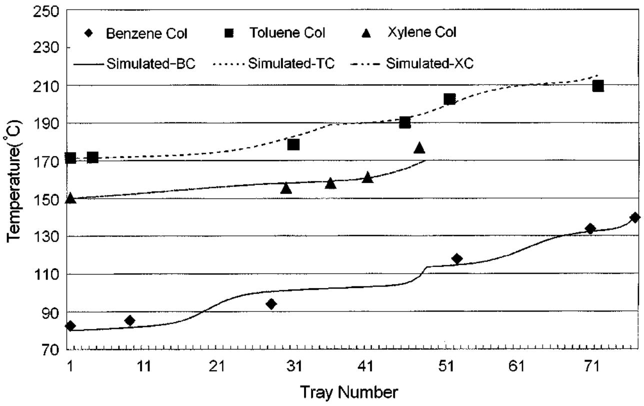

Fig. 2. Comparison of the simulated temperature profiles with real temperature data.

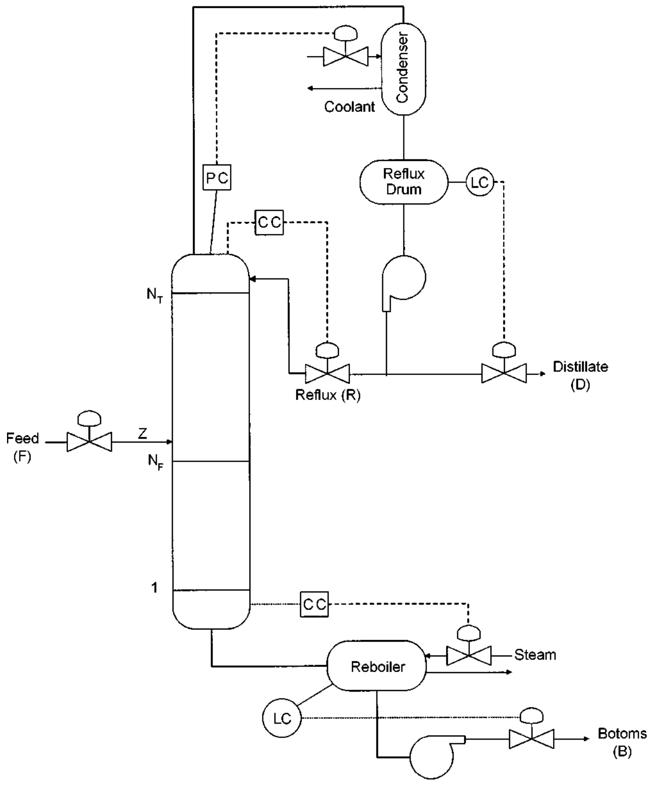

Fig. 3. A dual composition control system.

in Fig. 4. These calculations were performed for a fixed tray number, N_T, and constant feed tray, N_F. This column has 25 trays with the feed tray located at the 21st tray. The top curves in Fig. 4 show the V/F and R/F ratio values for various feed compositions when the DCC system was applied. Toluene and E-benzene are light-key and heavy-key components, respectively. Impurities of the light-key at the bottom and the heavy-key at the top are both 0.05 mole fraction. At this case, the maximum V/F ratio is 3.14 at about X_F= 0.4, and maximum R/F ratio is 2.38 at about X_F=0.35. These ratios were used for the control systems with fixed V/F or R/F ratios described below.

Even though the dual composition control strategy requires the minimum energy consumption for purity controls in distillation columns, this control strategy leads to closed-loop stability difficulties by the interaction between the two composition control loops. Therefore, more control system equipment is required and capital investment and maintenance costs are increased. Economically, it is important to note that dual composition control is not needed in order to minimize energy consumption when feed rate changes occur [Luyben, 1975]. Throughput disturbances can be simply handled by ratioing reflux or heat input to feed rate while controlling one product composition. The top or bottom product is controlled, and the others automatically will be over purity spec because the ratio, R/F or V/F, is fixed at maximum. These control systems will be discussed in the next sections.

2. Control System with Fixed Vapor Boilup-to-Feed Rate Ratio

The vapor boilup rate is fixed with a maximum V/F ratio of 3.14,

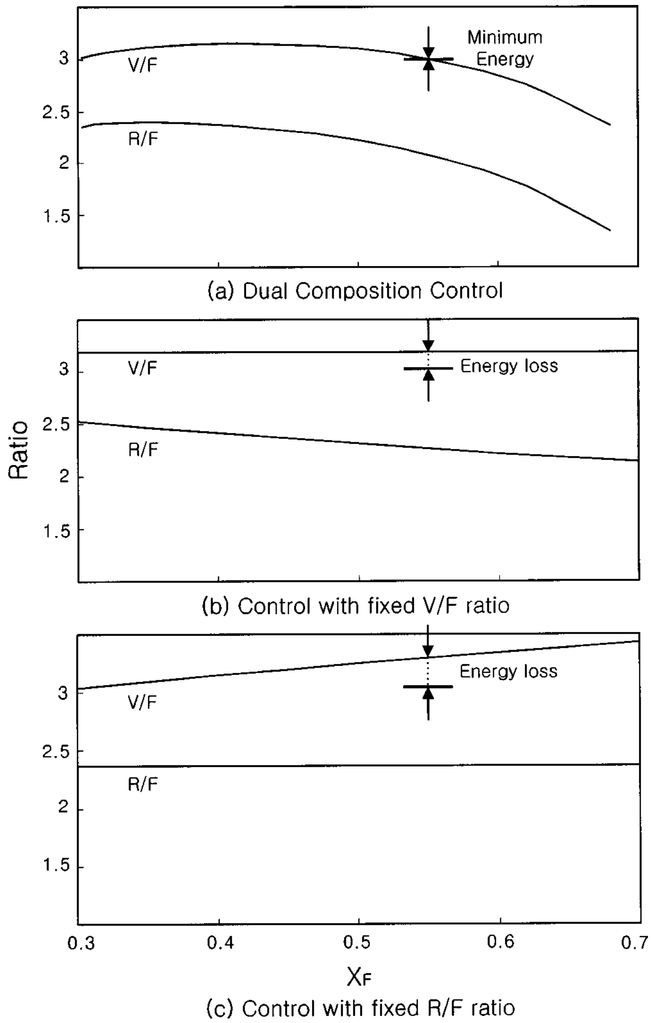

Fig. 4. V/F and R/F ratios for three different control systems.

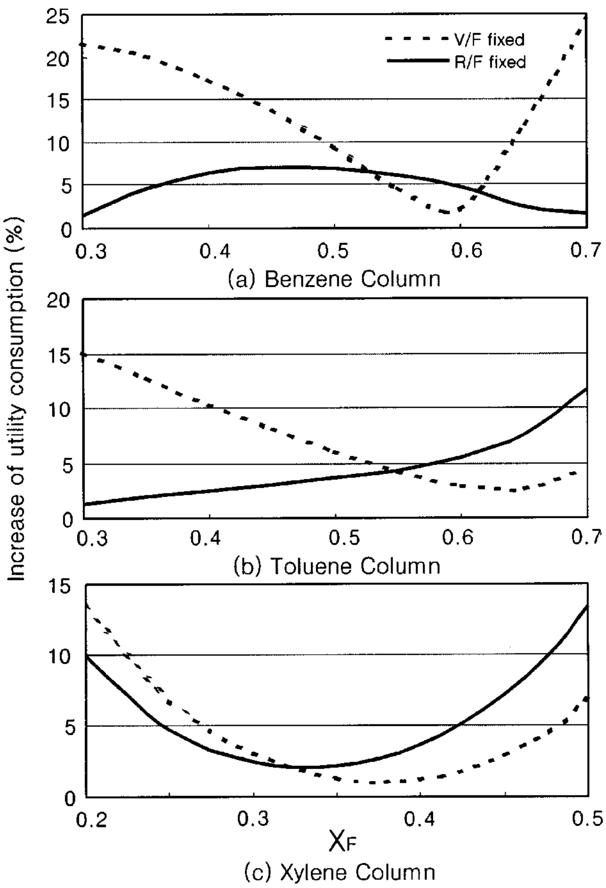

Fig. 5. Utility consumptions for different columns.

calculated in the DCC system, and the reflux rate is regulated to satisfy the top or bottom product purity. Since excess vapor boilup is being used, the composition of the uncontrolled product will always be better than standard purities. The middle curves in Fig. 4 show the R/F ratio changes for this control system. For example, at the light-key fraction in feed of about 0.54, the V/F ratio of 3.0 was required by DCC (refer to the top curves in Fig. 4). But the V/F ratio of 3.14 in this control system is 0.14 higher than the ratio using dual composition control. This represents a 4.7% increase in energy consumption for the feed composition of 0.54. For the feed composition is about 0.4, the energy consumption is minimized by the control system with fixed V/F ratio.

3. Control System with Fixed Reflux-to-Feed Rate Ratio

The reflux rate is fixed with a maximum R/F ratio of 2.38, calculated in the DCC system, and one product composition holds constant by manipulating the vapor boil-up. Since excess reflux is used, the uncontrolled product purity will always exceed specification. The bottom curves in Fig. 4 show the V/F ratio changes in the toluene column. At X_F=0.54, the V/F ratio is 0.29 higher (9.7%) than the DCC case. Thus, for the toluene column, the constant vapor boilup-to-feed control system is more efficient in energy consumption than the control system with fixed R/F ratio.

4. The Choice of the Control System with Fixed V/F or R/F Ratio

In order to guide the choice of the V/F or R/F fixed control systems, the percentages of increases of utility consumption compared to the DCC control system are shown in Fig. 5. The utility consumption includes the cost of steam to the reboilers and the cooling water to the condensers of the columns. As shown in the top curve of Fig. 5, the control system with fixed R/F ratio is recommended for the feed composition between 0.52 and 0.62 in the benzene column. For other feed compositions, a control system with fixed V/F ratio should be considered. In the toluene column, the control system with fixed R/F ratio is favorable when the feed composition is lower than 0.55. For the given feed compositions of about 0.5, the control system with fixed V/F ratio is recommended for the benzene and toluene columns, and the control system with fixed R/F ratio for the xylene column.

OPTIMUM FEED TRAY LOCATION

All of the previous calculations considered a fixed column with no change in the feed tray. It has long been recognized that the optimum feed tray location varies with feed composition. Clearly, the installation of other feed trays of the operating column is expensive; thus, several alternative feed trays are installed at the design step [Warren et al., 1999].

By varying the feed tray location, the V/F ratios of all the col-

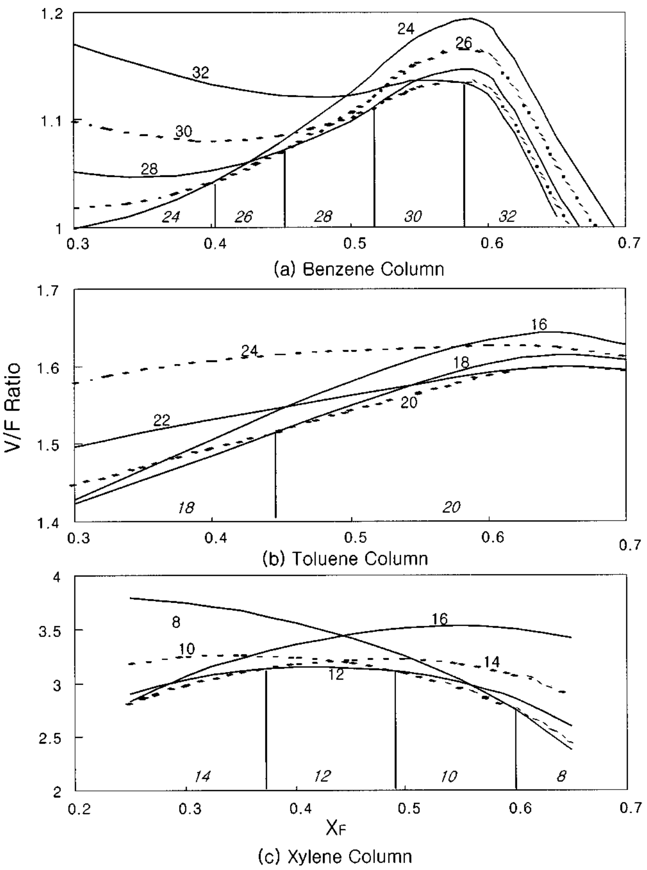

Fig. 6. V/F ratios for various feed trays at each feed composition.

umns were calculated and summarized in Fig. 5. In the benzene column, shown in the top curves in Fig. 6, the numbers on the various lines represent the feed tray locations and the numbers in the bottom are the optimum feed tray locations with X_F. The optimum feed tray locations are found to spend minimum energy consumption (minimum V/F ratio). The optimum feed tray locations are quite different for different feed compositions. The reduction in V/F ratio by using the optimum feed tray locations for each feed composition can be quite significant [Luyben, 1975]. In this case, for example, the V/F ratio calculated by using the 32nd feed tray is 10% higher than that using the 24th feed tray for the feed composition of 0.4. As shown in the middle curves of Fig. 6, the optimum feed tray location of the toluene column is the first tray for the lower feed compositions and the 20th tray for the higher feed compositions. In the xylene column, shown in the bottom curve of Fig. 5, the optimum feed tray location is found around the 12th tray. In the benzene and toluene columns, the optimal feed tray locations are moved up the columns as X_F increases, but moved down in the xylene column. This result explains that the relationship between optimum feed tray location and feed composition depends on product compositions and relative volatilities.

For typical fractionation units, the results of Fig. 5 were applied to calculate the amount of utility saved by using the optimum feed tray location. As shown in Table 2, the total energy consumption was reduced by about 16% compared to that by using the current feed tray locations.

Table 2. Calculation of the energy saving for a typical fractionation unit

	Real feed tray	Optimum feed tray
BC CondQ	3505	2628
BC RebQ	555.6	312.3
TC CondQ	191.7	190.9
TC RebQ	1963	1953
XC CondQ	498.6	495
XC RebQ	358.5	354.5
Total(kW)	7072.4	5933.7
Remarks	base	−16.1%

CONCLUSION

The operating strategies and optimum feed tray location were studied for a typical fractionation unit in a BTX plant from an energy saving standpoint. Alternative control methods could be chosen to minimize the energy consumption for producing the standard products. The control systems with fixed V/F or R/F ratios could be recommended for the various feed compositions. By choosing the optimum feed tray location for the columns, about 16% of energy consumption was reduced. The study for energy saving in this paper could help revamp or redesign the existing process.

ACKNOWLEDGMENT

Financial support from the Korea Science and Engineering Foundation and Konkuk University is gratefully acknowledged.

REFERENCES

Hyprotech, *HYSYS* Reference Manual, Vol. 1-2, Canada (1998).

Kim, Y. H., "Design of a Fully Thermally Coupled Distillation Column Based on Dynamic Simulations," *Korean J. Chem. Eng.*, **17**, 570 (2000).

Luyben, W. L., "Steady-State Energy Conservation Aspects of Distillation Column Control System Design," *Ind. Eng. Chem., Fundam.*, **14**(4), 321 (1975).

Noda, H., Takamatsu, T., Aso, K., Nakanishi, T., Oshida, K., Nakaiwa, M., Mukaida, T. and Kuratani, N., "Development on a Coaxial Heat Integrated Distillation Column (HIDiC)," *Korean J. Chem. Eng.*, **17**, 593 (2000).

Seo, J. W., Kim, S. J., Kim, K. H., Oh, M. and Lee, T. H., "An Optimal Design of Crude Distillation Unit: Part 1. Determination of Optimal Feed Tray Locations," *HWAHAK KONGHAK*, **39**, 1 (2001).

Tolliver, T. L. and McCune, L. C., "Distillation Column Control Design Based on Steady State Simulation," *ISA Transactions*, **17**(3), 3 (1978).

Warren, D. S., Seader, J. D. and Daniel, R. L., "Process Design Principles. Synthesis, Analysis, and Evaluation," John Wiley & Sons (1999).

Zaki, M. L. and Yoon, E. S., "The Energy Saving Effects of Complex Heat-Integrated Distillation Configurations," *Korean J. Chem. Eng.*, **6**, 185 (1989).