

고효율 증류탑의 설펴레인 공정에의 응용

김만철¹, 김병철², 김영한^{1,*}
동아대학교 화학공학과¹
경남정보대학교 신소재화공계열²
(yhkim@mail.donga.ac.kr*)

Application of energy-efficient distillation column to Sulfolane process

Man Cheol Kim¹, Byoung Chul Kim² and Young Han Kim^{1,*}
Dept. of Chemical Engineering, Dong-A University¹
Sub. of Adv. Mater. & Chem. Eng, Kyungnam Coll. of Info. & Tech.²
(yhkim@mail.donga.ac.kr*)

1. Introduction

The benzene separation from the reformat of catalytic cracker, a major blending material of octane booster of gasoline, has been widely implemented. The conventional process of benzene separation is composed of solvent extraction of aromatic compounds from of the reformat followed by the distillation of aromatic compounds to separate the benzene [1]. In the practical process of the aromatic compounds separation, minor processes of product washing are added in the summarized process [2]. The reformat from the catalytic cracker contains various non-aromatic compounds and typical aromatic compounds of benzene, toluene and xylenes. The listed components are in order of boiling points. Because the components around the benzene have close boiling points with benzene, a simple distillation of the reformat does not separate benzene from the others. Therefore the extraction of aromatic components is necessary prior to the distillation given at the end.

The extraction process is inefficient in terms of energy consumption. Large amount of recycled feed from the stripper and high boiling point of solvent require a large energy demand of high cost. When the benzene separation from the reformat is targeted for the use of gasoline blend, the extraction feedstock in the conventional process can be reduced by introducing a separation process in front of the extraction process as illustrated in Fig. 1. The reduction of feedstock directly lowers the load of extraction process requiring 72% of total energy demand in the process.

When the reformat composition is considered, four groups of components are formulated with key components of *n*-hexane, benzene, toluene, and xylenes. Therefore, an energy-efficient extended DWC is placed prior to the extraction process in this study. The comparison of the two processes indicates that the distillation column at the end in the conventional system is placed at the beginning of the proposed process. In the next sections the performance of energy saving, economics and thermodynamic efficiency improvement of the proposed process is examined by comparing with the conventional process.

2. Process Design

The process introduced in the references is slightly simplified for the convenience of simulation by eliminating two refining processes of minor components removal. The design and simulation of the process were conducted with the HYSYS. The thermodynamic equilibrium used in the simulation was computed with the UNIQUAC activity model. Most of the binary parameters of the UNIQUAC model are given in the software, and others are from the references. Because sulfolane and water are polar compounds, the available thermodynamic models of vapor-liquid and liquid-liquid equilibrium for the polar compounds are limited to the NRTL and UNIQUAC equations. Due to the availability of binary interaction parameters of the UNIQUAC model, the model was used in this study. The provided

parameters are not shown here because of the proprietary information of Aspen Technology. The conventional separation system of aromatic compounds from the naphtha reformat was derived from a practically-operated process, of which the detailed information was given in the references.

The main difference between the conventional and proposed systems is the location of benzene separation process. In the proposed system, the process of benzene separation is placed before the extraction process to reduce the extraction load. The utilization of the extended DWC in the benzene separation as the first process is determined after considering the distribution of feed components. The feed components are classified four groups by checking the distribution of boiling points and the combination of non-aromatic and aromatic components. When a conventional distillation system is employed in the group separation, three binary columns are necessary for the separation. In the separation of benzene group only, the last column will not be necessary because of no necessity of the separation of toluene and xylenes. In the application of the extended DWC, which is more energy-efficient than the conventional system, the separation of toluene and xylene was not tight to reduce the energy requirement. If the conventional distillation system is employed in the separation of benzene, two columns are necessary: one for lighter products than benzene and the other for benzene. The design target of the extended DWC is that the recovery of benzene in the side product is 99.5%. The design basis was adopted from the design of the extended Petlyuk column, and the iterative simulation was conducted to find the minimum energy demand. The design of extractor, stripper and solvent regenerator were similar to the conventional system design except the last distillation column used for the benzene separation.

3. Results and Discussion

The design results of the proposed benzene separation system are presented and compared with those of the conventional system. The investment and operating costs were compared, and the thermodynamic efficiency of the proposed system was analyzed to compare with the conventional system.

3.1 Design results

The results of the conventional process introduced in the references were not exactly simulated here due to the difference of the binary model parameters and minor modification of the process. The comparison of the process diagram and computed output indicate that the structural information and operating variables listed in Table 1 are close to the references. Some of operating process data, especially heat duty, were not given in the references, and they were found from the simulation for the performance comparison with the proposed system.

The design results of the proposed benzene separation system are included. The conventional and proposed processes are equally composed of four unit operations. The three operations of extraction, stripping and solvent regeneration, are the same in both processes. The difference is that the distillation separation of benzene is the last in the conventional system, while it is separated in the first operation with the extended DWC in the proposed system. The difference of reboiler duty in the distillation operation is noticeable. The DWC consumes 20.7% less energy in the reboiler, when the reboiler and feed heater duties are combined in the conventional system. Note that the amounts of the initial feed and final benzene production and the final benzene purity are close in the two systems. The DWC processes 36.7% more feed than the distillation column in the conventional process, because the feed in the conventional process handles aromatics only. However the loose specification control in the DWC reduces the energy demand significantly. The group including benzene is refined in the next three operations in the proposed system. Table 1 gives the structural and operating conditions of the extended DWC.

More significant reduction of energy demand is found from the solvent regeneration. Because the proposed process separates benzene only, the mixture containing most of benzene in feed is separated from others before introducing to the high-cost operation of extraction. The conventional processes of

aromatics separation do not practice the separation before extraction. The BTX separation process utilizes the extraction first, and the benzene separation process also applies the extraction first. In case the feedstock contains high concentration of benzene the heavy components in the feed are separated first using a conventional distillation column. By applying four-group separation using the extended DWC in this study, the heating duty of the whole process including feed heating was reduced by 56.8% compared with the conventional system, and the cooling duty reduction is 64.6%. In the comparison the benzene separation are aimed in the two systems. If the heat requirement in the conventional system, which separates benzene, toluene and xylene from the reformat, is limited to the benzene separation only, its heat requirement becomes 55.3% of the total, which is the product ratio of benzene in all products from the distillation column of the conventional system. In that case, the reduction of heat duty of the proposed system is 31%. A similar analysis is applied to the cooling energy requirement, and 36% reduction is found.

3.2 Economic evaluation

The economics between the conventional separation system and the proposed system is compared in terms of investment and utility costs. The results of economic evaluation are summarized in Table. The investment cost includes the costs of column, trays, and heat exchangers calculated from the cost equations given in Appendix. The total investment cost of the proposed separation process is 26% less than that of the conventional system. The cost reduction is largely from the cost reduction of the stripping column and solvent regeneration cost. The columns process the extractant and solvent, the amount of which is significantly larger in the conventional system than the proposed system. The early separation of benzene in the proposed system is designed for the benefit of cost reduction.

The reduction of utility cost is also expected in the proposed system. Table lists the utility cost of coolant and steam in the conventional and proposed systems, and shows that 56% less cost is necessary in the proposed system compared with the conventional system. The reduction is also from the early separation of benzene and heavy processing cost of solvent due to its high boiling point, which requires expensive steam of high pressure.

4. Conclusions

A new benzene separation process from the reformat of catalytic reformers is proposed, and its energy saving, economics and thermodynamic efficiency are evaluated to compare with the conventional process. The proposed process utilizes an extended divided wall column (DWC) for the feedstock reduction in the extraction column, which lowers the load of the whole process of benzene separation. The detail of the process design of the proposed process is explained. The computed results indicate that the proposed process saves 56.8% of heating duty over the conventional process and that of cooling duty is 64.6%. The economic analysis shows that the 26% reduction of investment cost and 56% reduction of utility cost are yielded from the proposed process compared with the conventional system. The thermodynamic efficiency is not significantly improved in the proposed process due to the large exergy loss in the solvent regeneration column.

References

1. Choi YJ, Kwon TI, Yeo YK. Optimization of the sulfolane extraction plant based on modeling and simulation. *Korean J Chem Eng* **17**, 712-718 (2000).
2. Cho J. A Study on the Simulation of Toluene Recovery Process using Sulfolane as a Solvent. *Korean Chem Eng Res* **44**, 129-135 (2006).

Table 1. Structural information, operating conditions and compositions in the conventional and proposed systems of benzene separation. Tray numbers are counted from top.

Variable	Conventional				Proposed			
	Extrt.	Strip.	Regen.	Distil.	DWC	Extract.	Strip.	Regen.
Structural					Main			
Tray No.	40	30	25	60	110	44	40	20
Feed Tray	20	1	10	30	75	36	1	10
Operating								
Press.(MPa)- top	6.3	2.1	0.5	1.0	1.16	4.0	2.1	0.5
Temperature (°C)								
Overhead	74.5	112	46.1	75.5	71.1	75	103	56
Bottom	76.1	148	270	127.5	155	130	115	251
Feed (kmol/h)	241.4	1040	873.7	175.1	239.3	123	602	382
Product (kmol/h)								
Overhead	78.8	166.6	208.1	93.3	22.6	31.5	220	93.5
Bottom	1040	873.7	665.6	75.3	26.4	602	382	282
Side					123			
Reflux (kmol/h)	747	1015	567	370	463	305	456	30
Vap. (kmol/h)	160.2	177.1	882	366	413	25.3	96.3	284
Cooling (MW)		1.48	9.03	4.56	3.89		0.25	1.2
Reboiler (MW)		3.09	15.46	3.45	3.91		1.29	5.61
Feed heater (MW)		2.22		1.48			0.3	
Comp. (ms. frac.)								
Feed (Benzene/ Toluene ⁺)	0.333/ 0.368	0.108/ 0.072	0.074/ 0.072	0.462/ .469	0.333/ 0.368	0.701/ 0	0.249/ 0	0.169/ 0
Product	Btm	Btm	Ovhd.	Ovhd.	Side	Btm	Btm	Ovhd.
Benzene	0.108	0.074	0.462	0.943	0.701	0.249	0.169	0.960
Toluene ⁺	0.072	0.072	0.469					
Solvent	0.751	0.839				0.584	0.821	

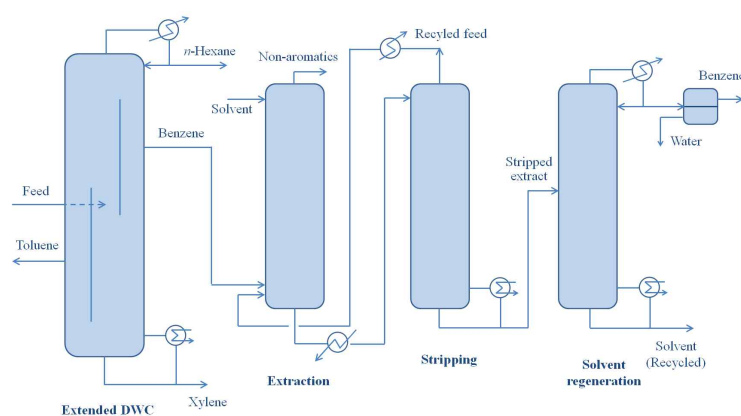


Fig. 1. Schematic diagram of the proposed process of benzene separation.