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Double-Effect Distillation Column with Internal Heat Integration

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1. Introduction

There are two heat exchangers—a reboiler and a condenser—equipped in a conventional distillation column. Though one of them consumes heat and the other releases heat, it can not be recycled due to the negative temperature difference between them. In practice the heat integration occurs between different distillation columns after consulting their operating temperatures. A heat-integrated distillation column within the column, the internally heat-integrated distillation column (HIDiC), utilizes the energy removed from the upper section of the binary column, rectifying section, in order to heat its lower section, stripping section [1]. Recently, the heat-integration with external heat exchangers has been proposed: between condenser and reboiler[4] and between trays in rectifying and stripping sections [5]. These systems use two or three heat exchangers, while the HIDiC has the heat exchanger in every paired tray.

In this study, a double-effect distillation system utilizing an internally heat-integrated column is proposed to replace a conventional binary column for the reduction of energy requirement, and its design and operation are explained here. The performance of energy conservation of the proposed system is examined with two example processes. In addition, the thermal efficiency of the proposed system is compared with that of the conventional distillation system.

2. Column Structure and Design

In a binary distillation column the heat integration is accomplished by operating columns at different pressures as shown in Figure 1, and it is known as the internally heat-integrated distillation column (HIDiC) [2]. In the practical application the difficulty caused by the compressor utilization has been indicated from the field engineers to introduce a new HIDiC without the compressor utilization [3]. Instead of raising the operating pressure of the rectifying section, the operating pressure of the stripping section is reduced using a vacuum pump between the two sections of the heat integration.

The tray-by-tray heat integration as demonstrated in Figure 2 lowers the pressure difference between the two columns, and the diabatic operation—though a half of each column involved—improves the efficiencies of the distillation system. The improvement will be calculated in later section. The conceptual heat integration of Figure 2 can be materialized by the introduction of an internally heat-integrated distillation column as given in Figure 3. Note that the heat integration occurs partially. The rectifying section of the first distillation column and the stripping section of the second are left as they are. The structural design of the proposed distillation system is directly adopted from the original column except the internally heat-integrated column. Namely, the first and last sections of the system use those of the sections in the numbers of trays of the original column. In practice the existing column can be utilized as one of the sections, though the number of trays is larger than the design of the new system. Unless the numbers of trays in the rectifying and stripping sections of the original distillation column are quite different, the number of trays of the heat integrated column can be determined as the smaller number between the two sections.

3. Results and discussion

The heat removed from the rectifying section of a distillation column can not be recycled to heat its own stripping section due to the negative temperature difference. When two distillation columns process the feed of a single binary column in a half each, the necessary temperature difference can be generated applying different pressures to the columns. The performance of energy saving and the thermal efficiency are examined and compared with those of the conventional distillation system. The total number of trays of the conventional system is taken as the sum of tray numbers of the two columns in the proposed system.

The comparison results of exergy loss and thermal efficiency between the proposed and conventional systems in the benzene-toluene process are listed in Table 1. The exergy loss was calculated from the enthalpy-Carnot factor diagram shown in Figure 4. The top demonstrates for the first column of the heat-integrated distillation system, and the bottom does for the second. The exergy values of feed and products are obtained from the HYSYS simulation. The tray-by-tray heat integration is responsible to the efficiency increase. Because the reboiler temperature found from the HYSYS simulation is close to the temperature of bottom product and the enthalpy of the product is much larger than the reboiler duty of the first column as shown in the top plot of Figure 4, the exergy loss in the reboiler becomes zero.

The proposed distillation system in this study utilizes separate condensers and reboilers in the columns, which help the column operation. Though the two columns are thermally connected, the separate manipulation of the four heat exchangers gives easy control of the pressure and temperature of the columns. The column pressure can be adjusted with the condenser duty, and the individual column is operated with a separate condenser. While the temperature at the top tray is controlled with the reflux flow rate, and that of the bottom is done with the reboiler duty in the same manner as in the control of a conventional distillation column. Therefore, the operation of the proposed system is as simple as the conventional column.

4. Conclusion

An internally heat-integrated distillation column is proposed for the double-effect distillation, and its performance of energy saving and thermal efficiency are compared with those of the conventional distillation column. Using two identical binary columns the heat integrated system for a ternary separation developed previously has been applied to the binary separation. Two examples of the benzene-toluene and methanol-ethanol processes are used for the performance evaluation. The performance comparison indicates that the proposed system requires a 17.4 % less of reboiler duty and 22.5 % less of condenser duty for the benzene-toluene process and 15.8 % less of heating duty and 17.3 % less of cooling duty for the methanol-ethanol process. The thermal efficiencies are 16.3 % and 23.8 % for the benzene-toluene and methanol-ethanol processes, respectively, which are much higher than those of the conventional distillation system. In the proposed system no compressor is utilized to eliminate the problem caused by the compressor and the separate reboilers and condensers for each column give easier operation than the original internally heat- integrated distillation column.

References

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Table 1. Exergy losses in the proposed, existing double effect and conventional distillation systems for the benzene-toluene process. Units are in GJ h^{-1}.

Process	Proposed		Double effect		Conventional
	1st	2nd	1st	2nd	
Trays	0.518	0.251	0.687	1.032	0.149
Condenser	0.485	0.150	0.503	-0.212	0.897
Reboiler	0	0.599	0.023	0	1.228
Preheater		0.296		4.502	
Total		2.299		6.534	2.274
Feed	0.828		0.828		0.828
Overhead	0.121	0.253	0.118	1.793	0.241
Bottom	0.339	0.562	0.322	0.716	0.728
Min. work		0.447		2.120	0.141
Thermal Efficiency (%)		16.3		24.5	5.8

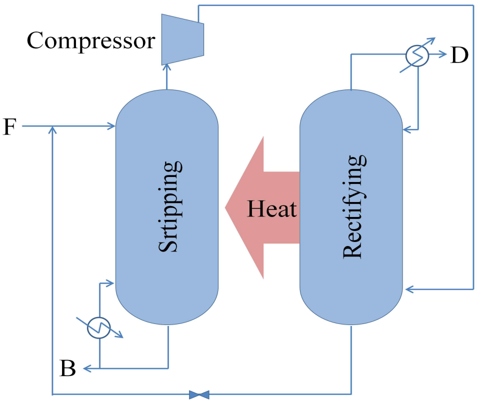


Figure 1. Schematic diagram of an internally heat-integrated distillation column.

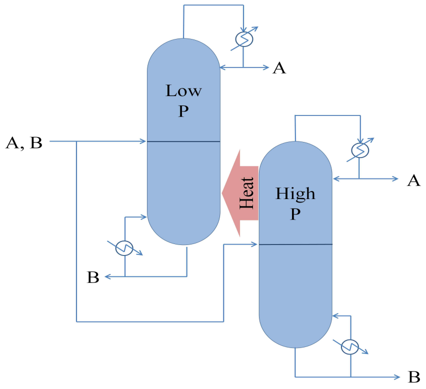


Figure 2. A conceptual schematic of a double-effect internally heat-integrated distillation column.

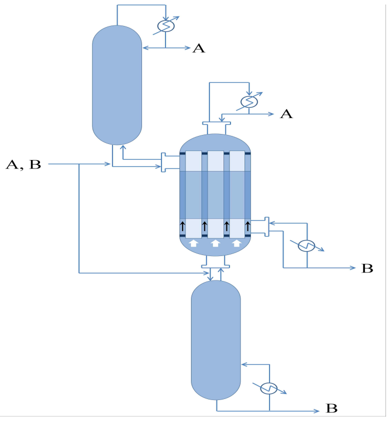
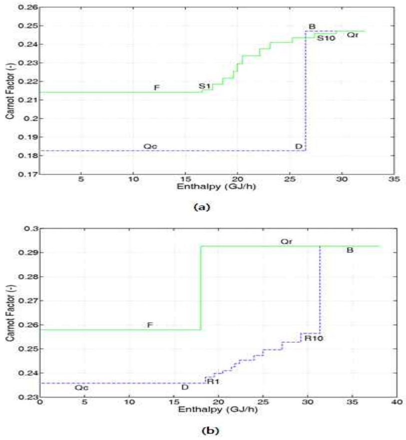


Figure 3. Schematic diagram of a double-effect internally heat-integrated distillation column for practical application.



(a)

(b)

Figure 4. Enthalpy-Carnot factor diagram of the heat-integrated distillation in the benzene-toluene process: (a) 1st column (b) 2nd column.