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Energy Saving Performance of Internal Heat-Integrated Batch Distillation

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A model for an internally heat-integrated batch distillation column (Batch or Semi-batch HIDiC) was developed, and the separation of a benzene-toluene binary mixture was simulated.
The applicability of the model was examined by using the commercial process simulator Aspen Plus Dynamics® to evaluate energy-saving performance and process time against the compression ratio and reflux ratio. The batch or semi-batch HIDiC model results were compared with the conventional batch distillation model. It was found that with the semi-batch HIDiC, the model has the potential to reduce process time and energy consumption more precisely than the conventional batch distillation model.

1. Introduction

Energy-saving processes offer the most promising next-generation technology for distillation with acceptable environmental characteristics and inexpensive process cost (Humphrey, 1995). So far, separation process research has been usually carried out by a conventional distillation process. Recent estimates, which put distillation energy demands closer to 40 % of the total energy requirement, indicate that obtaining the maximum energy efficiency is important.
For this reason, several energy-saving methods, such as intermediate heat exchanger process (Agrawal and Herron, 1998) and vapor re-compression column system (VRC) (Schmal et al., 2006) have been developed to overcome the disadvantage of conventional distillation processes.
However, these involve a complicated process to obtain the energy savings and required an initial cost. Recently, internally heat integrated distillation columns (HIDiC) was studied as a way to achieve energy saving (Nakaiwa et al., 2005; Iwakabe et al., 2006).

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The HIDiC has a rectifying and a stripping section, a reboiler, and a condenser.
In addition, a compressor and a throttling valve are equipped for the HIDiC, with a pre-heater or a valve cooler, or both. The pressure of the vapor flowing up from the top of the stripping section is elevated by the compressor, and the pressure of the liquid flowing down from the rectifying section is lowered by the throttling valve.
If the temperatures for the rectifying and the stripping section are different from each other and these two sections are contacted through a dividing wall, the temperature difference between the two sections produces a driving force for the heat transfer.
This decreases the required reboiler heat duty and the vapor and liquid flow rates inside the column, and enhances the degree of energy utilization in a distillation column.
In the first national HIDiC project, Naito et al. (2000) have been reported that the bench plant of the HIDIC was achieved 30 % energy reduction for the separation of benzene-toluene binary mixture.
In the present study, the batch HIDiC model is developed. The objective of the present study is to use this model to derive the batch procedure of HIDiC separating a mixture of Benzene-Toluene binary system.

2. Simulation model

Table 1 indicates the simulation conditions of the design and operating variables. The phase equilibrium calculation was applied with assumption of the ideal. Basic material, enthalpy balance and heat transfer equations are described elsewhere (Iwakabe et al., 2005).
The simulation analysis was made by use of a process simulator Aspen Plus Dynamics®.
As shown in Figure 1, the basic flow configuration of the batch HIDiC system was altered to a twin column (a rectifying column and a stripping column) type model to carry out the computer simulation. An imaginary two types of bessele was installed on bottom (named batch HIDiC) and middle (named semi-batch HIDiC).

Table 1: Design and operating conditions of calculation

Number of stages	10	stages
N_H	5	stages
N_L	5	stages
Feed location from middle vessel	5	stage
Pressure of the top of low pressure section	101.3	kPa
Vapor flow rate of 1st stage	136.4	kg/h
Isentropic efficiency of compressor	0.72	—
Liquid level of tray	0.1	m
Initial condenser holdup	3.0	m^3
—Liquid holdup	0.03	m^3
—Vapor holdup	2.97	m^3
Initial tray holdup	0.48	m^3
—Liquid holdup	0.06	m^3
—Vapor holdup	0.42	m^3

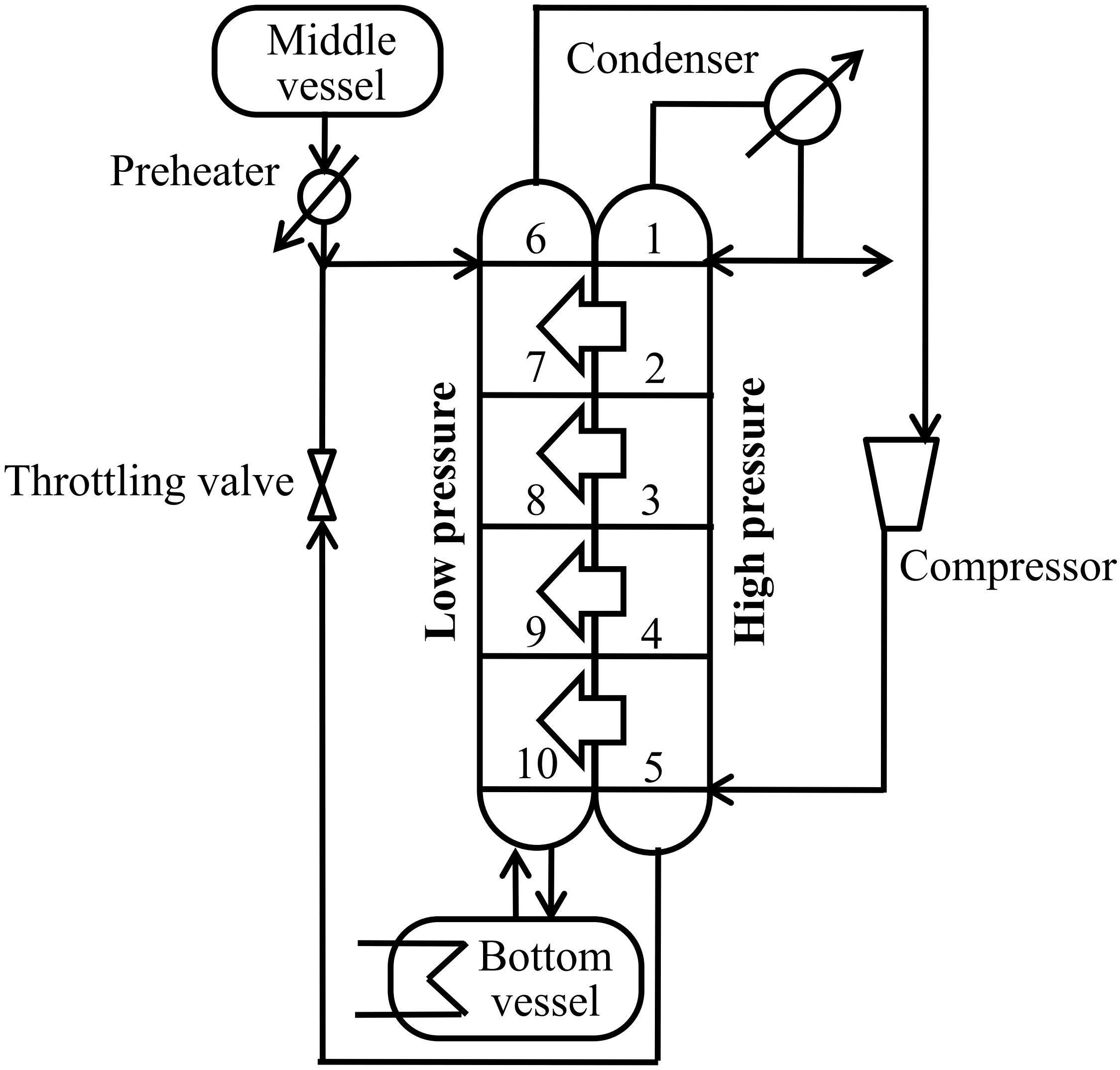

Figure 1: A schematic diagram of the batch or semi-batch HIDiC

3. Results and discussion

Figure 2 shows the predicted temperature and flow rate profiles along the column. The ordinate is the temperature and mol flow rates of vapor and liquid, and the abscissa is the number of stages. It can be clearly seen that, the vapor and liquid flow rates increases as from the bottom to the top in the stripping section.

In rectifying section, on the other hands, the flow rates decreases as from the bottom to the top. It is exhibited the evaporation of liquid in the rectifying section and the condensation of vapor in the stripping section.

Their phenomenon was occurred because of heat exchange along the tube unit between rectifying and stripping sections.

The results of the energy saving evaluation are shown in Table 2. The energy saving rate remarkably decreases with the process time.

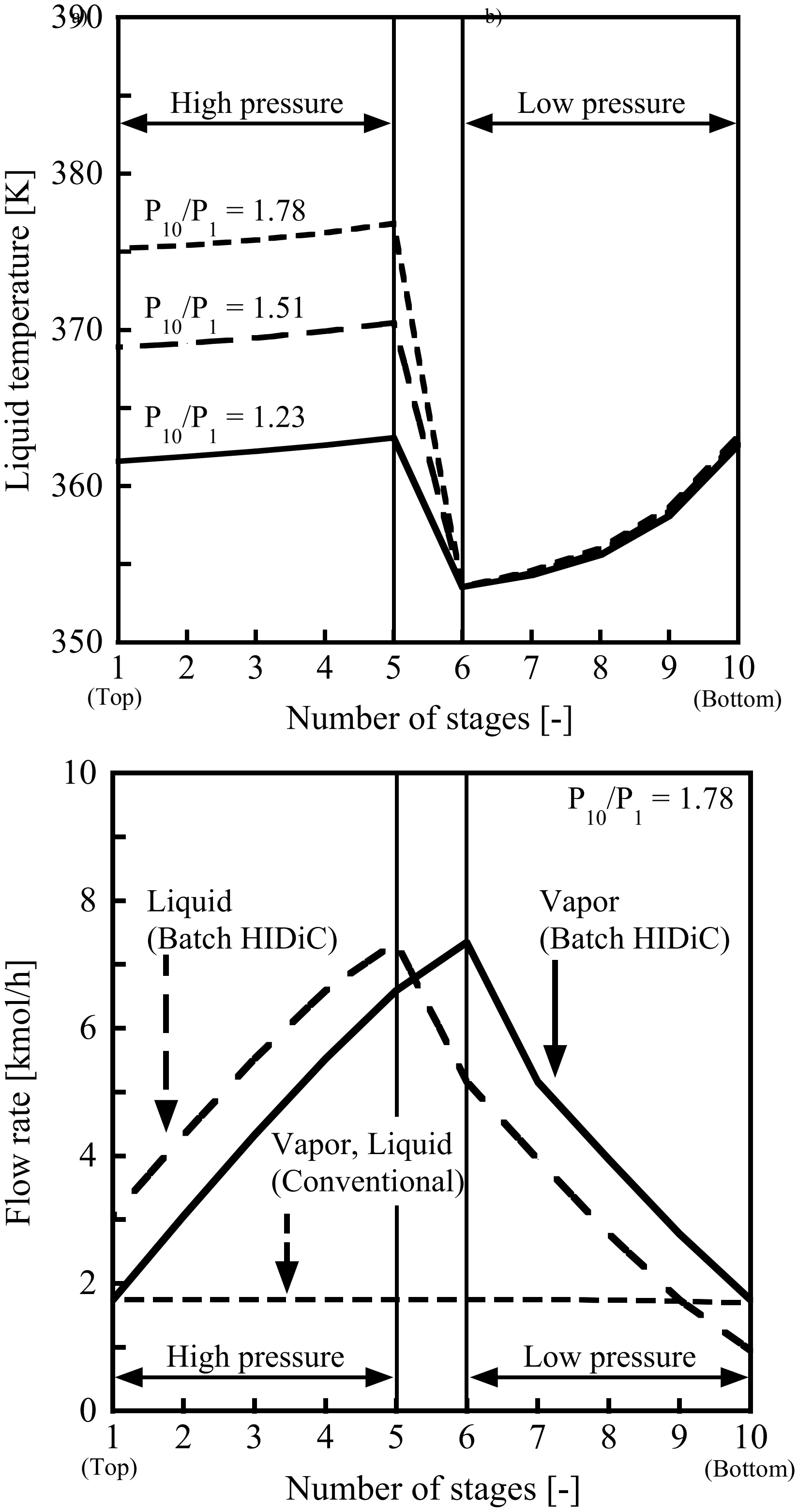

Figure 2: Liquid temperature (a) and flow rate (b) on profiles along the column for the present model

Table 2: Energy consumption for the batch HIDiC systems and conventional column

	Compression ratio [-]	Reflux ratio [-]	Feed [kmol/h]	Process time [h]	Energy consumption [GJ]
Batch HIDiC	1.60	1.50	—	30.5 (+0.9 h)	1.66 (+3.1%)
Semi-batch HIDiC	1.60	0.78	1	21.7 (-7.9 h)	1.25 (-22.4 %)
Conventional	—	1.43	—	29.6 (Base)	1.61 (Base)

4. Conclusions

In this study, computer-aided analysis of energy saving by the bathc HIDiC was conducted on a process simulator Aspen Plus Dynamics.
The application of the HIDiC technology to the dynamic batch process was simulated and energy consumptions of the batch or semi-batch HIDiC were compared with that of the conventional distillation column. In the semi-batch HIDiC, energy saving rate of 22% was expected if the HIDiC is operated at the compression ratio of 1.6.

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