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Energy efficient optimal design of waste solvent recovery process in semiconductor industry using enhanced vacuum distillation

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Abstract

Semiconductor is one of the biggest industries in the world because it is the key driver of economic growth and it is continuously growing in a cyclical pattern. Huge amount of various chemicals have been used in the process, but it is not followed by a good waste treatment. This results in high production cost and inflicts on environment because of most of the valuable organic solvents discharged from the process has been incinerated at high temperature. In this work, optimal distillation process configuration was examined to recover valuable organic solvents and to cut down the production-related costs as well as to protect the environment against the industrial wastes. In this distillation process, some columns in a conventional sequence were optimized by using a box optimization algorithm to obtain minimum energy consumption without violence some constraints and then, main product columns were optimized in the economical point of view by a Particle Swarm Optimization (PSO) method. To achieve further objective of energy improvement with high profit, thermally coupled distillation and heat pump assisted distillation were implemented as alternatives of conventional distillation column with low energy efficiency. The results showed that the proposed advanced column configuration could save energy and utility consumption significantly.

Keywords: Waste solvent; Waste treatment; Distillation; Thermally coupled distillation; Heat pump assisted distillation; Optimization

1. Introduction

Semiconductor industry is one of largest industry and has more than $304 billion market nowadays, and representing close to 10% of world GDP. The global semiconductor industry is dominated by USA, South Korea, Japan, Taiwan, Singapore, and European Union. South Korea has market share about 9% and has been declared as one of the most important as well as the growth powers of the nation [1]. In

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manufacturing, this industry uses plenty amounts of solvents and is not treated in the most economic way. Waste solvents are incinerated at very high temperature around 700 °C. High energy costs and secondary pollutants from incineration facility are problematic and the environmental hazards to human life and ecosphere. To solve this problem from a cost and environment point of view, several methods are proposed to recycle or to recover organic solvents, and distillation is one of most plausible and practical solutions. In order to obtain a good distillation system, a systematic design procedure is necessary. In this work, enhanced distillations for waste solvent recovery will be presented with a systematic optimization strategy.

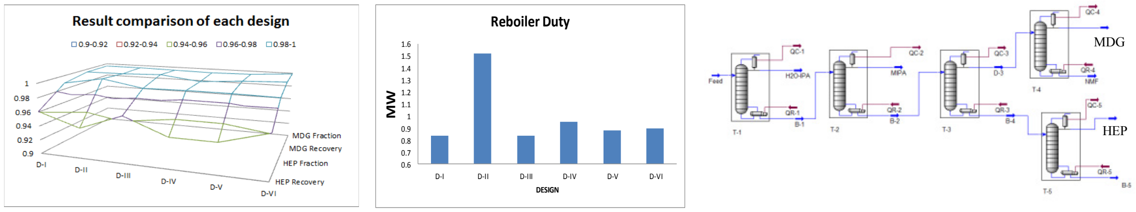
2. Process development

Laboratory experiment was conducted to identify components of waste solvent. The result showed mixture composition, separation feasibility and also includes process constraint. Temperature constraints was below 190 °C and each component purity constraints was 98% of weight except water. Component of waste solvent is introduced as a feed composition [2].

Table 1. Feed composition in mass %

MDG	HEP	IPA	MIPA	NMF	H2O	PR
33	21	3	12	15	12	4

Aspen Hysys v7.3 as one of powerful simulation tools for chemical processes was used to simulate the distillation sequence. The NRTL fluid package was used as a thermodynamic method of simulation. The UNIFAC method was applied to estimate the missing parameters of NTRL system. Each column was operated in vacuum distillation to satisfy temperature constrains. Main product are MDG and HEP. Several conventional sequences were simulated and only the best case in terms of main component purity, recovery and reboiler duty was then further optimized. Design III (D-III) was considered as best result.



(a) (b) (c)

Fig. 1. (a) comparison among conventional sequences; (b) reboiler duty comparison; (c) recommended design of conventional sequence (D-III)

Distillation has several variables to be optimized. In order to optimize the conventional sequence in Fig.1(c), column 1, 2 and 3 was optimized based on the criterion of reboiler duty minimization. Because one column had influent to other columns in this distillation system, the column result should be under constraint, otherwise, final target product would not be satisfied and recovery was smaller. A well known Box method was used to optimize column 1, 2 and 3 because it was already implemented in Aspen Hysys. Fig.2 describes a procedure of column optimization. Column 1 optimization must meet the constraints in column 1, 2, 3, 4 and 5. In the next column optimization, column 2 optimization must meet also the constraints in column 2, 3, 4 and 5. Similarly, column 3 optimization must meet those in column 3, 4 and 5.

Table 2. Overall constraints

Column 1(C1)	Column 2(C2)	Column 3(C3)	Column 4(C4)	Column 5(C5)
Top temperature < 80 C Bottom temperature < 188.9 C H2O Mass Flow Top > 118 Kg/h	Mass Frac MIPA > 98.9% Bottom temperature < 188.9 C	Bottom temperature < 188.9 C	Mass Frac MDG > 98.9% Mass Frac NMF > 98.9% Bottom temperature < 188.9 C	Mass Frac HEP > 98.9% Bottom temperature < 188.9 C

Optimization of heat duty of the column can be stated as Min (Q) = f (R, P_0, T_F, N_F, N_T), where R denotes the reflux ratio; P_0 the column pressure; T_F the feed temperature; N_F the feed stage number; N_T the number of column stages. These five variables were used only in the first column because T_F for the next column was defendable variables from the previous column. Only four variables were adjusted for next columns: R, P_0, N_F, *and* N_T.

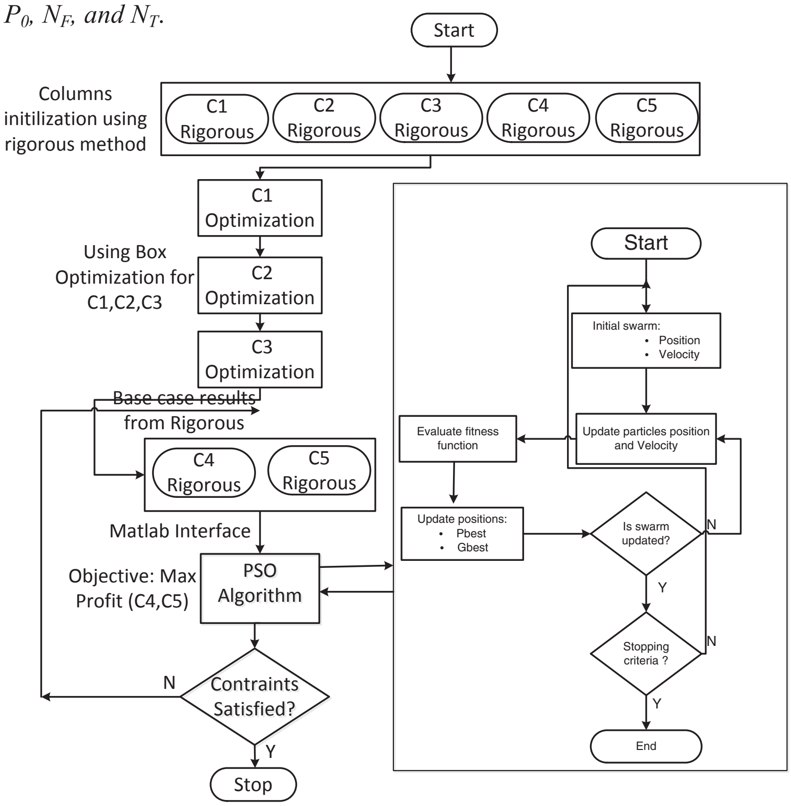


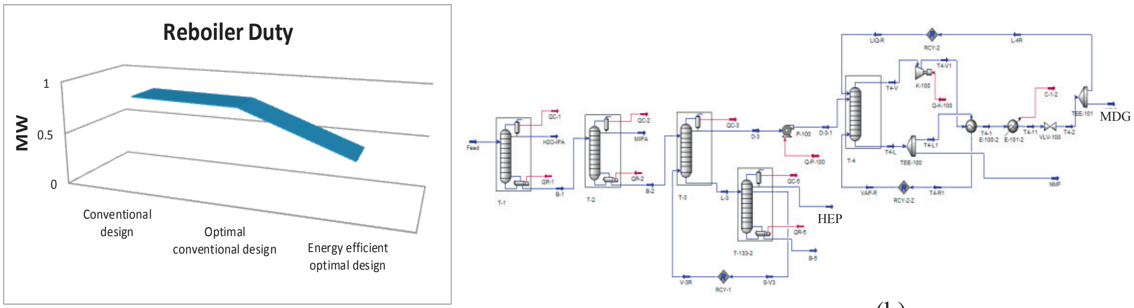
Fig. 2. Optimization procedure

Column 4 and 5 are main product columns. Particle swarm optimization was implemented to this section to maximize profit. Process simulator generates all variables needed for profit maximization. External optimization solver (PSO) including the objective function and all needed code were coded in

Matlab. Component Object Model (COM) by Microsoft acts as an intermediate to make a communication between Aspen Hysys and Matlab, in which Aspen Hysys acts as a calculation engine [3]. Objective function for C4 and C5 is Max (P) = $f\,(R, P_0, N_F, N_T)$, with Max (P) = [(HEP Flow* \$ HEP + MDG Flow* \$ MDG)- \$ Utility]. Reboiler duty of column 4 and 5 was obtained once a maximum profit was achieved, and then the optimal conventional column was improved in terms of total reboiler duty of distillation using thermally coupled distillation and heat pump assisted distillation.

3. Result and Conclusion

The results showed that optimal conventional design had slightly energy improvement. It was caused by strict constrains of each column. Energy efficiency could be more improved by utilizing advanced column. Proposed advanced configuration of optimal design could achieve a significant energy saving of 45% in comparison with the optimal conventional design.



(a) (b)

Fig. 3. (a) overall reboiler duty of each design; (b) energy efficient optimal design

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Biography

Yus Donald Chaniago is a PhD Candidate in Process Systems Design and Control Laboratory (PSDC Lab.) at School of Chemical Engineering, Yeungnam University, South Korea. Currently he is working on distillation intensification especially energy efficiency improvement and azeotropic system