Design of Energy Efficient Distillation Columns Systems

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KEYWORDS: Energy Efficient Distillation Columns, Driving Force, Pinch Technology

Distillation is the primary separation process widely used in the industrial chemical processing. Although it has many advantages, the main drawback is its large energy requirement, which can significantly influence the overall plant profitability. However, the large energy requirement of these processes can be systematically reduced by using driving force and energy integration methods. This paper presents a methodology for designing energy efficient distillation columns systems based on those two methods. Accordingly, the proposed methodology consists of four hierarchical steps. In the first step, the system of distillation columns for multicomponent separation is designed based on the conventional distillation column design (shortcut) method. Then, the conventional distillation columns systems design is improved in terms of energy saving by using driving force method in the second step. It is expected in the third step that the distillation columns systems design can be further improved in terms of energy saving by using energy integration method. Finally, the distillation columns systems design is evaluated in in terms of economic performance. The simulation results by using Aspen HYSYS have shown that the direct sequence (Benzene and Toluene) for BTX (Benzene, Toluene and p-Xylene) has energy savings with 8% reduction by using driving force method compared to a shortcut method. It can be verified that the proposed methodology has the capability in designing energy efficient distillation columns in an easy, systematic and practical manner.

1. Introduction

The demand for energy has been continuously increasing for years and operation units with large energy demand such as distillation columns have become more difficult to be supplied. The energy efficiency of distillation columns systems becomes an important criterion during retrofitting and design of industrial chemical processes. On the other hand, reducing energy requirements of distillation column systems leads to lower CO_2 emission. This becomes the reason why the plant designer must take the different energy saving solutions into consideration and choose the best distillation columns systems design for the specific separation task.

Reducing product cost in chemical industry has been very effectively used in energy saving method for distillation columns by heat integration columns system. Heat integration by two columns is based on an idea to match utilizing overhead vapour of one column in order to provide heat content for boiling up a second column. Heat integration column is the process of hot streams was heat exchanged with cold streams. In this process the rectifying and stripping sections was designed by internally coupled through heat exchanger. These designs have proven an enormous improvement by reducing the reboiler and condenser duties will lead to energy saving efficiency. Therefore, the development of process and energy integration technique have been developed such as the fully thermally coupled distillation columns (FTCDC or Petlyuk column) and dividing wall columns (DWCs), which can have greater in reduce energy consumption. The divided wall column allows reversible splits with no part of the separation being used twice and the main source of its superior energy efficiency over other column configurations. However, Petlyuk systems have strong interactions between their columns because of the thermal integration, which can inhibit their design and operation.

Therefore, a new methodology that will enable to design energy efficient distillation columns (EEDCs) is proposed in this paper. Accordingly, the proposed methodology consists of four hierarchical steps. In the first step, the system of distillation column for multicomponent separation is designed based on the conventional distillation column design method. Then, the conventional distillation columns systems design is improved in terms of energy saving by using driving force method in the second step. It is expected in the third step that the distillation columns systems design can be further improved in terms of energy saving by using energy integration method. Finally, the distillation column systems design is evaluated in in terms of economic performance. By applying the proposed methodology, it is possible to make an early assumption on sequence of distillation column systems that is the best in terms of energy saving. Significant energy savings can be made with the use of distillation column trains with driving force [1] and energy integration [2] methods.

Bek-Pederson and Gani [1] developed a systematic design and synthesis of distillation systems using a driving force based method.

This method suggested that at the highest driving force, the separation becomes easiest due to the large difference in composition between the phases and therefore, the energy necessary to achieve the separation task at each individual distillation column is at a minimum. In addition, Sobocan et al. [3] developed a systematic synthesis of energy integrated distillation column systems. This method helps in reducing external energy input of the distillation column systems by minimizing the utility consumption and maximizing the heat exchange between the integrated columns.

This paper presents a methodology for designing energy efficient distillation column systems based on driving force and energy integration methods. In the next section, review on energy integrated distillation columns design is discussed followed by a detail of the proposed methodology which consists of four hierarchical steps. The application of this methodology is tested by using a case study and ends with conclusion.

2. Overview of Energy Integrated Distillation Columns Design

The design method for energy integrated distillation columns can be summarized into four types which are: 1) conventional type distillation column with multicomponent separation, 2) conventional type distillation column with driving force, 3) conventional type distillation column with pinch technology and 4) conventional type distillation column with driving force combining with pinch technology. The McCabe-Thiele graphical technique has been used as a basic and simple technique to determine the design values of distillation column [4].

In this study, two graphical methods are used to determine the optimal design for energy efficient, which are driving force and pinch technology. Driving force method usually uses in the earliest stage of designing distillation column in order to successfully achieve the desired separation. In distillation column, driving force is the difference between composition in vapour phase and liquid phase which occurs when the difference of properties such as boiling point and vapour pressure [5]. The ideal designs for distillation column is based on the driving force approach to maximum, will lead to energy necessary in maintaining the two phase system in minimum or highly energy efficient design. Therefore, in the second type of distillation column design, the driving force method will be used as an additional step in similar conventional distillation column with the present of driving force diagram.

Meanwhile, pinch technology represent as a simple thermodynamically method that produce minimum energy consumption by using the first key of pinch analysis (setting energy target) as a key part for energy monitoring [6]. Pinch technology method helps to optimize the heat transfer equipment during temperature crossover between hot streams and cold streams according to the first and second law of thermodynamics. Then, the third type of distillation design method is achieved by using pinch technology in the conventional type of distillation column in order to reduce energy consumption in the process which mean more energy saving can be obtained. Lastly, the design of energy efficient distillation column can be created by combining driving force method with pinch technology in the conventional type of distillation column. Theoretically, by combining these two methods with the conventional type of distillation columns can produce more energy efficient.

3. Methodology for Designing Energy Efficient Distillation Columns Systems

In this section, we discuss in more details the development of a systematic methodology for designing energy efficient distillation columns systems based on driving force and energy integration methods. Accordingly, the proposed methodology consists of four hierarchical steps as shown in Fig 1.

The first step deals with the conventional distillation columns systems design, which will become the base design used for verification purposes. In this step, the system of distillation column for multicomponent separation is designed based on the conventional distillation column design method. Then, the conventional distillation columns systems design is improved in terms of energy saving by using driving force method in the second step. It is expected in the third step that the distillation columns systems design can be further improved in terms of energy saving by using energy integration method.

Finally, the distillation column systems design is evaluated in in terms of economic performance. By applying the proposed methodology, it is possible to make an early assumption on type of distillation column systems design that is the best in terms of energy saving and cost.

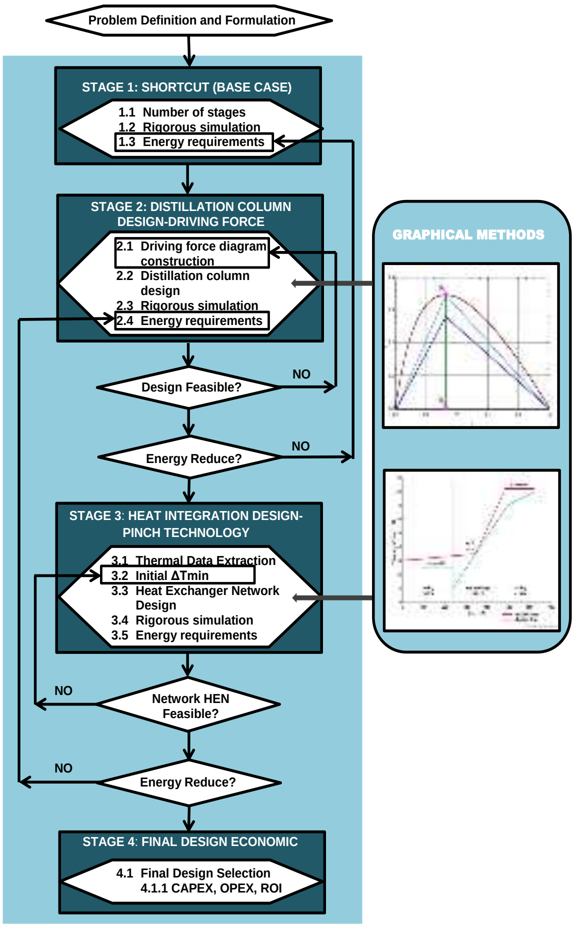

Fig. 1: A new proposed methodology for an energy integrated distillation columns.

The simulation models of the studied distillation columns systems are implemented in the Aspen HYSYS process simulator. In the first step, the number of the theoretical trays, location of the feed trays and the reflux ratio are estimated with shortcut design procedure. The results of the shortcut design are then implemented in rigorous column model. In the second step, by fixing the number of the theoretical trays obtained in the previous step, the location of the feed trays and the reflux ratio are estimated by using driving force method. Then, the results of the driving force design are implemented in rigorous column model, and the total energy consumption is compared with the previous shortcut design. In the third step, the energy saving of the distillation columns systems designed by driving force method is further improved by implementing energy integration. The design of the heat exchanger network is synthesized by using thermal pinch method. The results of the heat exchanger network design are then implemented in rigorous column model, and the total energy consumption is compared with the two previous designs. Finally, the economic performance is calculated and analyzed.

4. Case Study for Benzene, Toluene and p-Xylene (BTX)

The separation case study of a ternary mixture of benzene, toluene and p-xylene is selected to highlight the application of the proposed methodology as shown in Table 1. The feed flowrate is 100kmol/hr and products consist of three components. In this case study, A, B and C are denoted as light, intermediate and heavy components. The temperature and pressure for feed are selected at 75 °and 2 atm.

In the first stage, the separation sequence based on the short cut design method is applied. The energy required for this separation sequence is taken as a reference. Then, the energy requirements for the separation is verified or further improved by using driving force method.

Table 1: Case study of flow rate feed and product specification.

Streams	Feed	
Components	kmol/hr	X
Benzene (A)	50.00	0.50
Toluene (B)	30.00	0.30
p-xylene(C)	20.00	0.20
Total	100	1.00

Fig 2 shows the driving force diagrams for two different binary separations which are Benzene-Toluene (direct sequence) and Toluene-p-Xylene (indirect sequence). From the figure, it can be seen that the plot of Benzene-Toluene shows the higher point compared to Toluene- p-Xylene. According to the driving force method, at the higher point at the driving force diagram separation becomes easier and the energy required to maintain that separation is at the minimum. Therefore, by just analysing the driving force diagram, we can identified the best distillation columns sequence that will require less energy.

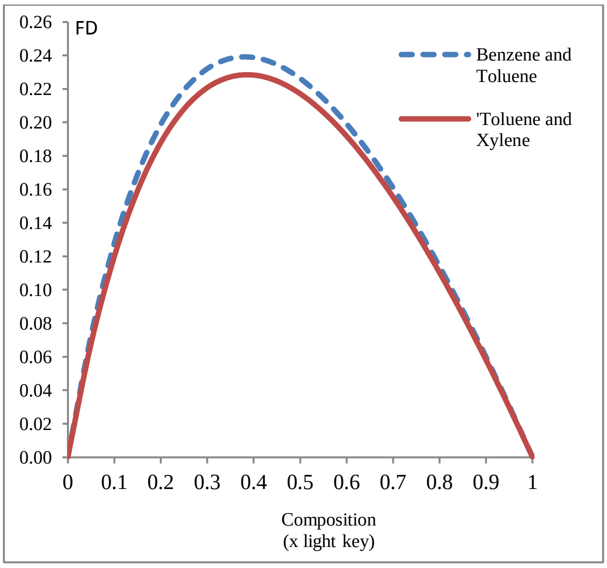

Fig 2: Driving force diagram for BTX separation system.

The sequence obtained from the driving force method will be then verified in terms of energy saving by using Aspen HYSYS process simulator. Tables 2 and 3 show the results for the percentage of energy savings for indirect and direct sequences by using Aspen HYSYS simulations. It is verified that energy saving with 8% reduction can be obtained by using direct sequence as suggested by the driving force method.

5. Summary

The methodology for designing energy efficient distillation column systems based on driving force and heat integrated methods has been presented. Accordingly, the proposed methodology consists of four hierarchical steps. By applying the proposed methodology, it is possible to make an early assumption on the sequence of distillation column systems that is the best in terms of energy saving.

Table 2: Separation of Toluene and p-Xylene (Indirect Sequence)

Design		Shortcut Method	Driving Force Method
No. of stages, N_S		24	24
No. of feed location, N_F		10	15
Reflux Ratio		0.628	0.507
Composition at top	Benzene	0.6023	0.6122
	Toluene	0.3697	0.3651
	p-xylene	0.0100	0.0227
Composition at bottom	Benzene	0.0000	0.0000
	Toluene	0.0100	0.0100
	p-xylene	0.9900	0.9900
Energy Condenser, kW		2161	2098
Energy Reboiler, kW		2292	2229
Total Energy, kW		4453	4327
Percentage Energy Saving with Driving Force Method, %		3	

Table 3: Separation of Benzene and Toluene (Direct Sequence)

Design		Shortcut Method	Driving Force Method
No. of stages, N_S		21	21
No. of feed location, N_F		10	13
Reflux Ratio		1.421	1.070
Composition at top	Benzene	0.9900	0.9900
	Toluene	0.0100	0.0100
	p-xylene	0.0000	0.0000
Composition at bottom	Benzene	0.0100	0.0415
	Toluene	0.5900	0.5714
	p-xylene	0.4000	0.3871
Energy Condenser, kW		1809	1663
Energy Reboiler, kW		1937	1792
Total Energy, kW		3746	3455
Percentage Energy Saving with Driving Force Method, %		8	

Acknowledgement

The financial support from Universiti Teknologi Malaysia is highly acknowledged.

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