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# Methodology Development for Designing Energy Efficient Distillation Column Systems

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## Abstract

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 development for designing energy efficient distillation column systems based on those two methods. 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.

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*Keywords:* Distillation column design; driving force method; pinch technology; energy efficient.

## 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

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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 column systems design for the specific separation task. 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 development for designing energy efficient distillation column systems based on driving force and energy integration methods. In the next section, a detail of the proposed methodology which consists of four hierarchical steps is discussed. The application of this methodology is tested using simple distillation columns design, and this paper ends with the conclusion.

## 2. 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 column 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.

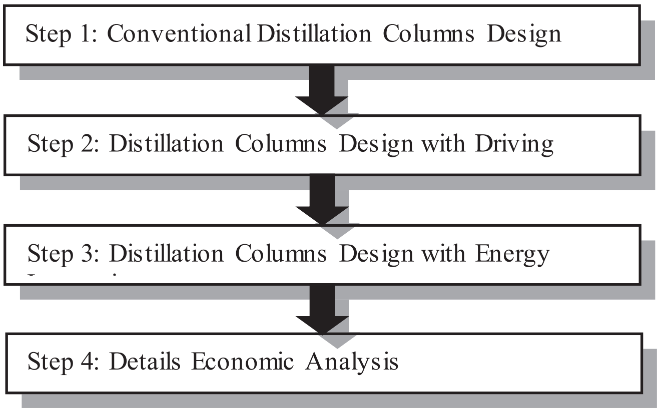

Fig. 1. Methodology for designing energy efficient distillation columns systems

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.

## 3. Case Study for Ethanol, n-Propanol and n-Butanol

The separation case study of a ternary mixture of ethanol, n-propanol and n-butanol was selected to highlight the capability of the proposed methodology. In this case study, A, B and C denoted as light, intermediate and heavy components, respectively. Pressure both columns are set as 101.33 kPa.

Fig. 2 shows the driving force plots for two different separations of binary systems which are n-propanol/n-butanol and ethanol/n-propanol. It can be clearly seen from the figure, n-propanol/n-butanol shows the highest driving force plot. Accordingly, separation system with higher driving force will have an easier separation compared with the lower one. Hence, energy required to maintain the separation is at the minimal [1]. Based on the driving force method, the sequence that will have lower energy requirement is indirect sequence (recovery of n-butanol in the first column).

Tables 1 and 2 shows the result for the percentage of energy savings for indirect and direct sequence by using Aspen HYSYS simulation. It is proven that indirect sequence have greater energy savings with 16% reduction by using this driving force method compared with shortcut method.

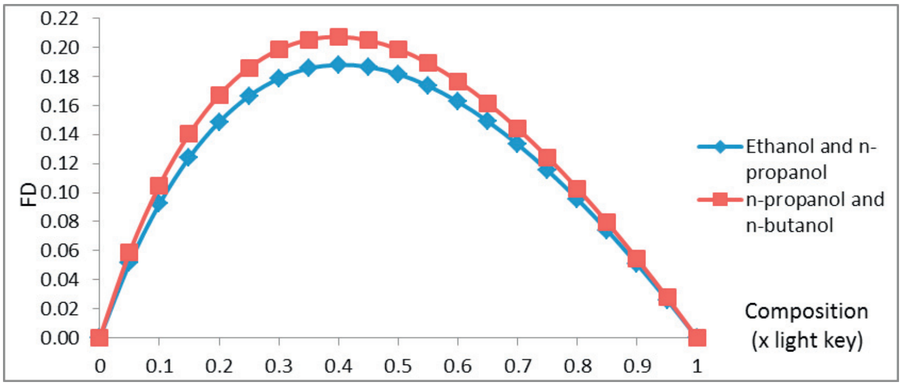

Fig. 2: Driving Force for Ethanol, n-Propanol and n-Butanol

## 4. Summary

The development of 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.

| **Design** | | **Shortcut Method** | **Driving Force Method** |
|---|---|---|---|
| No. of stages, $N_S$ | | 35 | 35 |
| No. of feed location, $N_F$ | | 30 | 21 |
| Reflux Ratio | | 1.077 | 0.356 |
| Composition at top | Ethanol (A) | 0.5025 | 0.4576 |
| | n-Propanol (B) | 0.4974 | 0.4539 |
| | n-Butanol (C) | 0.0001 | 0.0885 |
| Composition at bottom | Ethanol (A) | 0.0000 | 0.0000 |
| | n-Propanol (B) | 0.0100 | 0.0100 |
| | n-Butanol (C) | 0.9900 | 0.9900 |
| Energy Condenser, KW | | 2740 | 2308 |
| Energy Reboiler, KW | | 2845 | 2408 |
| Total Energy, KW | | 5585 | 4716 |
| Percentage Energy Saving with Shortcut Method, % | | - | 16 |
| Percentage Energy Saving with Driving Force Method, % | | -18 | - |

Table 1: Separation n-Propanol and n-Butanol (Indirect Sequence)

| **Design** | | **Shortcut Method** | **Driving Force Method** |
|---|---|---|---|
| No. of stages, $N_S$ | | 21 | 21 |
| No. of feed location, $N_F$ | | 20 | 13 |
| Reflux Ratio | | 2.941 | 3.106 |
| Composition at top | Ethanol | 0.9900 | 0.9900 |
| | n-Propanol | 0.0100 | 0.0100 |
| | n-Butanol | 0.0000 | 0.0000 |
| Composition at bottom | Ethanol | 0.0100 | 0.0123 |
| | n-Propanol | 0.4925 | 0.4914 |
| | n-Butanol | 0.4975 | 0.4963 |
| Energy Condenser, KW | | 2723 | 2776 |
| Energy Reboiler, KW | | 2827 | 2880 |
| Total Energy, KW | | 5550 | 5656 |
| Percentage Energy Saving with Shortcut Method, % | | - | -2 |
| Percentage Energy Saving with Driving Force Method, % | | 2 | - |

Table 2: Separation Ethanol and n-Propanol (Direct Sequence)

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