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Minimum Energy Distillation Columns Sequence for Aromatics Separation Process

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Abstract

The objective of this paper is to present the study of the optimal synthesis of energy efficient distillation columns (EEDCs) sequence of aromatics separation process by using driving force method. In order to perform the study and analysis, the EEDCs sequence methodology is developed. Accordingly, the methodology consists of four hierarchical steps; Step 1: Existing Sequence Energy Analysis, Step 2: Optimal Sequence Determination, Step 3: Optimal Sequence Energy Analysis, and Step 4: Energy Comparison. The capability of this methodology is tested in designing minimum energy distillation column sequence for aromatics separation process. The results show that the maximum of 7.0% energy reduction was able to achieve by changing the sequence suggested by the driving force method. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for aromatics separation process in an easy, practical and systematic manner.

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Keywords: Energy efficient; distillation columns sequence; driving force method; energy analysis

Introduction

Distillation is the primary separation process widely used in the separation processing. However, in spite of its many well-known benefits and the widespread use, one major drawback is the significant energy requirements, which can significantly influence the overall plant profitability. There is no denying the fact that energy considerations will have a more significant impact on distillation design and retrofitting in the future. The determination of feasible sequences of multiple distillation columns, whether

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on the basis of minimum overall energy consumption, total annualized costs, sustainability, or some other metric, has been the subject of academic and industrial investigation for many years. The synthesis of distillation columns sequence for multicomponent feed mixtures has been a challenging problem in process design for several decades. A large number of researches have been conducted to highlight the advantages of a variety of methodologies for determining the best sequence from a given number component feed mixture. These include early methodologies such as the use of heuristics, genetic algorithms, mixed integer nonlinear programming (MINLP) methods and others [1].

Significant savings in the utilities for aromatics separation process can be achieved by using driving force method in innovative configurations. However, the conventional distillation columns may be used in aromatics separation design, and only the configurations/sequences need to be changed. This can be systematically and effectively achieved by using driving force method. For distillation column, the driving force can be defined as the difference in composition of a component *i* between the vapour and liquid phase due to the difference of properties such as boiling point and vapour pressure of component *i* and the others. Driving force can be measured by the binary pair of key multi-component mixture or binary mixture. Theoretically, when the driving force near to zero the separation of the key component binary mixture becomes difficult, while, when the driving force near to high peak or maximum value, the separation between two components become more easier [2]. Although this typical method makes separation process become efficient and systematic, it clear that it is only to determine the best sequence of the energy analysis instead of other parameters that can be determined together.

In this paper, the study and analysis of the energy saving improvement for the aromatics separation sequence by using driving force method without having any major modifications to the major separation units, is presented. There will be only modifications to the separation sequences based on the driving force results, which will reduce the energy requirement. To perform the study and analysis, the energy efficient distillation columns (EEDCs) sequence methodology is developed. Accordingly, the methodology consists of four hierarchical steps; Step 1: Existing Sequence Energy Analysis, Step 2: Optimal Sequence Determination, Step 3: Optimal Sequence Energy Analysis, and Step 4: Energy Comparison. We will illustrate some energy saving distillation columns sequence and present how the use of driving force method helps in determining the optimal sequence with less energy requirement.

Nomenclature

MINLP	Mixed Integer Nonlinear Programming
EEDCs	Energy Efficient Distillation Columns

2. Energy Efficient Distillation Columns Sequence Methodology

To perform the study and analysis of the energy saving improvement for the energy efficient aromatics separation sequence, EEDCs sequence methodology is developed based on the driving force method. Accordingly, the methodology consists of four hierarchical steps as shown in Fig 1.

In the first step, a simple and reliable short-cut method of process simulator (Aspen HYSYS) is used to simulate a base (existing) columns sequence. The energy used to recover individual fractions in the base sequence is analyzed and taken as a reference. In the second stage, an optimal columns sequence is determined by using driving force method. All individual driving force curves for all adjacent components are plotted and the optimal sequence is determined based on the plotted driving force curves. Details step-by-step algorithm in plotting the driving force can be obtained elsewhere [2]. The highest value of maximum driving force which corresponds to the splitting of the adjacent component will be separated first, while the lowest value of the maximum driving force will be separated last. According to the driving force method, at the highest value of the maximum driving force, the separation becomes easy and the energy required to maintain the separation is at the minimum. Whereas, at the lowest value of the maximum driving force, the separation becomes difficult and energy required to make the separation feasible is at the maximum [2]. Once the optimal sequence has been determined, the new optimal sequence is then simulated in step three using a simple and reliable short-cut method (using Aspen HYSYS), where the energy used in the optimal sequence is analyzed. Finally, the energy used in the optimal sequence is compared with the base sequence. The capability of this methodology is tested in designing minimum energy distillation column sequence for aromatics separation process, which consists of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, *o*-xylene, *m*-xylene) with five direct sequence distillation columns. This typical methodology generates systematically procedure that focus on aromatic separation compare to the method that founded by Bek-Pedersen (2004)

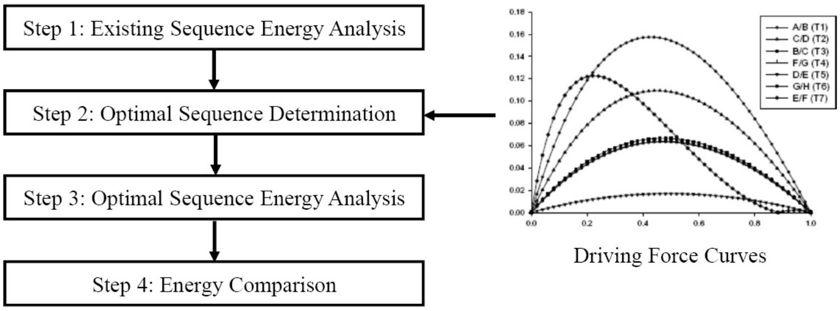

Fig. 1. Energy efficient distillation columns sequence methodology [2].

3. Case Study: Aromatics Separation Process

The capability of proposed methodology is tested in designing minimum energy distillation column sequence for aromatics separation process. The objective of the aromatics separation process is to recover individual fractions using a distillation columns. In this paper, we assumed that the existing aromatics separation process consists of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, *o*-xylene, *m*-xylene) with five direct sequence distillation columns.

3.1. Existing Sequence Energy Analysis

Fig. 2 illustrates the existing separation sequence (direct sequence) of the aromatics separation process. The feed composition, temperature and pressure are described in Table 1. The existing aromatics separation process was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 20.1 MW energy used to achieve 99.9% of product recovery.

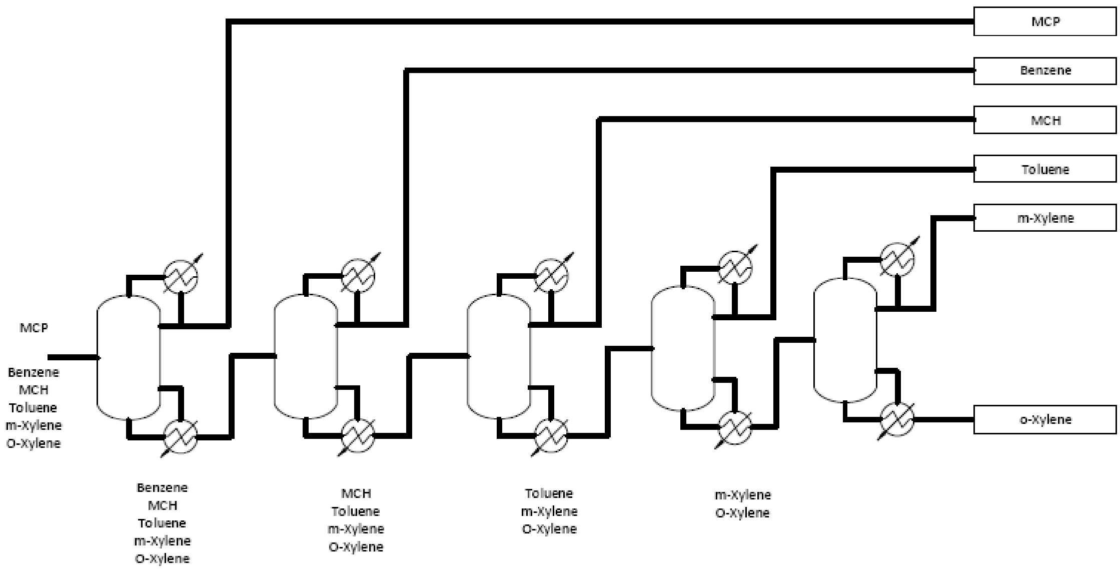

Fig. 2. Simplified flow sheet illustrating the existing direct sequence of aromatics separation process.

Table 1. Feed conditions of the mixture.

	Feed conditions
Components	Mole fractions
methylcyclopentane (MCP)	0.1
Benzene	0.1
methylcyclohexane (MCH)	0.1
Toluene	0.1
o-xylene	0.1
m-xylene	0.5
Temperature (ºC)	25
Pressure (atm)	1

3.2. Optimal Sequence Determination

The optimal aromatics separation sequence was determined by using driving force method. All individual driving force curves was plotted as shown in the Fig. 3, and the optimal sequence was determined based on the plotted driving force curves. The new sequence based on driving force is shown in the Fig. 4.

3.3. Optimal Sequence Energy Analysis

A new optimal sequence determined by driving force method (see Fig. 4) was simulated using a short-cut method within Aspen HYSYS environment where a total of 18.7 MW of energy was used for the same product recovery.

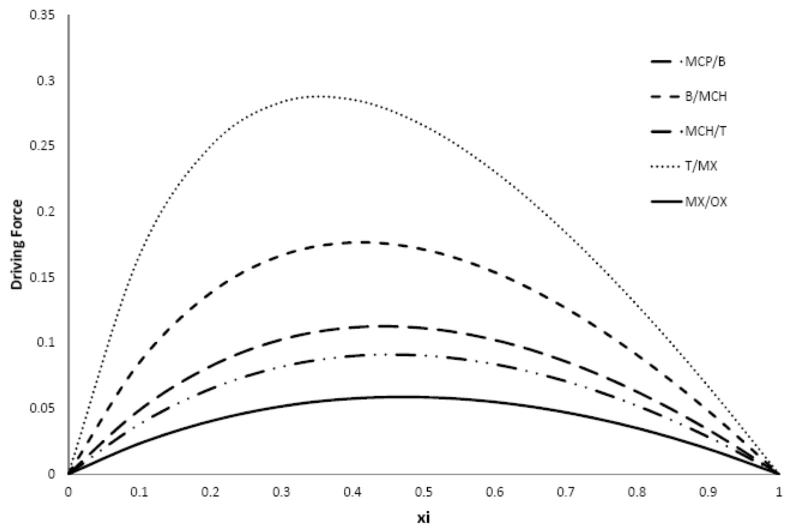

Fig. 3. Driving Force curves for set of binary component at uniform pressure.

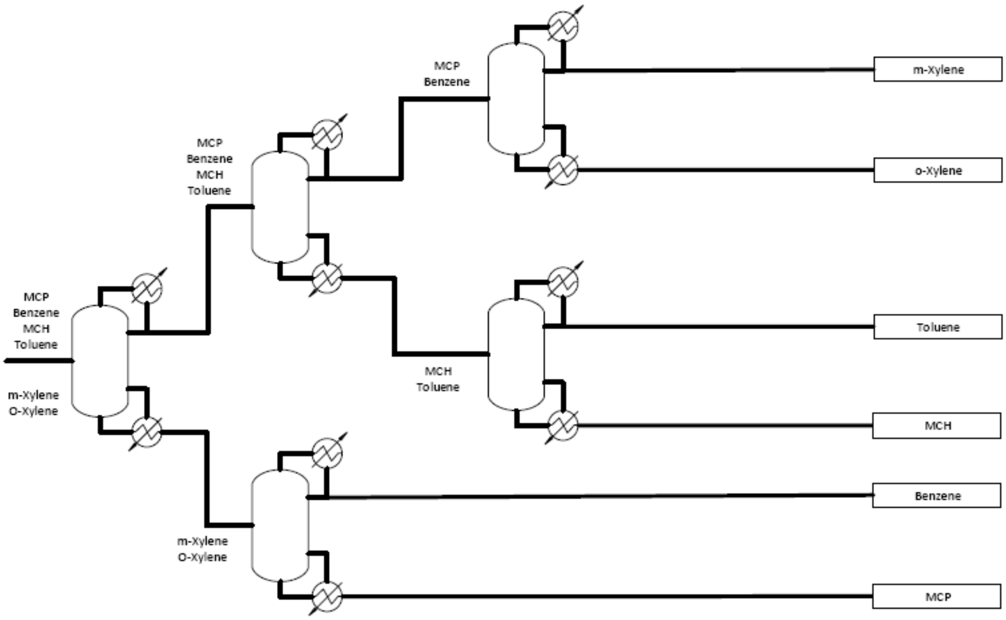

Fig. 4. Simplified flow sheet illustrating the optimal Driving Force sequence of aromatics separation process.

3.4. Energy Comparison

Total energy used to recover every single fractions for the existing direct sequence and the new optimal sequence determined by the driving force method is shown in Table 2. The results show that the maximum of 7.0% energy reduction was able to achieve by changing the sequence suggested by the driving force method. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for aromatics separation process.

Table 2. Energy comparison for direct sequence and driving force sequence for aromatics separation process.

	Direct Sequence	Driving Force Sequence	Percentage (%)
Total Energy Condenser (MW)	9.8	9.1	**7.0**
Total Energy Reboiler (MW)	10.3	9.6	**6.6**
Total Energy (MW)	**20.1**	**18.7**	**7.0**

4. Conclusion

The study and analysis of the energy saving improvement for the aromatics separation process by using driving force method has been successfully performed. The existing aromatics separation process consists of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, *o*-xylene, *m*-xylene) with five direct sequence distillation columns was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 20.1 MW energy used to achieve 99.9% of product recovery. A new optimal sequence determined by driving force method was simulated using a short-cut method within Aspen HYSYS environment where a total of 18.7 MW of energy was used for the same product recovery. The results show that the maximum of 7.0% energy reduction was able to achieve by changing the sequence suggested by the driving force method. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for aromatics separation process in an easy, practical and systematic manner.

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Biography

Mohd. Kamaruddin bin Abd. Hamid, is a Research and Development (R&D) Manager for Process Systems Engineering Centre (PROSPECT) UTM. He specializes in the area of integrated process design and control for chemical process applications and currently involves in developing a new methodology in designing energy efficient distillation columns.