Sustainable Energy Efficiency Distillation Columns Sequence Design of Aromatic Separation Unit

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• Abstract

(b) Distillation operations became a major concern within sustainability challenge, which it becomes a primary target of energy saving efforts in industrially developed countries. However, there is still one problem, which is how do we improve the energy efficiency of the existing distillation columns systems by considering the sustainability criteria without having major modifications. Recently, a new energy efficient distillation columns methodology that will able to improve energy efficiency of the existing separation systems without having major modifications has been developed. However, this developed methodology was only considered the energy savings without taking into consideration the sustainability criteria. Therefore, the objective of this paper is to present new improvement of existing methodology by including a sustainability analysis to design an optimal sequence of energy efficient distillation columns. Accordingly, the methodology is divided into four hierarchical sequential stages: i) existing sequence sustainability analysis, ii) optimal sequence determination, iii) optimal sequence sustainability analysis, and iv) sustainability comparison. In the first stage, a simple and reliable short-cut method is used to simulate a base (existing) sequence. The sustainability index of the base sequence is calculated and taken as a reference for the next stage. In the second stage, an optimal sequence is determined by using driving force method. All individual driving force curves is plotted and the optimal sequence is determined based on the plotted driving force curves. Then, by using a short-cut method, the new optimal sequence is simulated and the new sustainability index is calculated in the third stage. Lastly, in the fourth stage, the sustainability index for both sequences (base and optimal) is compared. The capability of this methodology is tested in designing an optimal sustainable energy efficient distillation columns sequence of aromatics separation unit. The existing aromatics separation unit consists of six compounds (Methylcyclopentane (MCP), Benzene, Methylcyclohexane (MCH), Toluene, m-Xylene and o-Xylene) with five direct sequence distillation columns is simulated using a simple and reliable short-cut method and rigorous within Aspen HYSYS simulation environment. The energy and sustainability analysis is performed and shows that the optimal sequence determined by the driving force method has better energy reduction with total of 6.78 % energy savings and 0.16 % sustainability reduction compared to existing sequence with. In addition, the economic analysis shows that the return of investment of 3.10 with payback period of 4 months. It can be concluded that, the sequence determined by the driving force method is not only capable in reducing energy consumption, but also has better sustainability index for aromatic separation unit.

Keywords. Energy efficient distillation column; Sustainability; Aromatic separation unit; Simulation.

1 Introduction

Significant savings in the utilities for chemical separation process can be achieved by using driving force method in innovative configurations. 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 [1]. However, this developed methodology did not consider sustainability aspect in the early of design stage. Distillation column design can be further improved by including sustainability aspect within the developed Energy Efficient Distillation Columns (EEDC) methodology to ensure that the design is controllable, as well as sustainable [2]. The sustainability performance of a system or chemical process is identify by metrics and indicators in order to evaluate the progress toward enhancing sustainability [3]. The sustainability indicator or also known as sustainability evaluator can be classify from environmental aspect, economic dimension, and societal equity condition into one, two and three dimensional metrics [4]. In this paper, the study and analysis of the sustainability and energy saving improvement for the aromatic mixtures separation sequence by using driving force method without having any major modifications to the major separation units, is presented. There will be modifications to the separation sequences based on the driving force results, which will reduce the energy requirement and addition of better sustainability index as well as the economic analysis.

2 Sustainable Energy Efficient Distillation Columns Sequence Design Methodology

To perform the study and analysis of the energy saving improvement as well as sustainability for the sustainable energy efficient distillation columns (Sustain-EEDCs) separation sequence, Sustain-EEDCs sequence methodology is developed based on the driving force method [1]. Accordingly, the methodology consists of four hierarchical steps. 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 short-cut method in the Aspen HYSYS simulation environment basically is a command operator in the software itself in order to estimate energy results of the process. The energy results from the process simulator is analysed in the sustainability evaluator to perform the sustainability analysis. The three-dimension (3D) sustainability index is used due to simplicity and reliability based on the case study that need to be conducted. The sustainability index of the existing sequence is taken as a reference for the next step. 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 [5]. 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 [5]. 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 by using Aspen HYSYS, where the 3D sustainability index for this optimal sequence is analysed based on the energy results from the simulation environment. Finally, the 3D sustainability index in the optimal sequence is compared with the base sequence.

3 Results and Discussion Case Study: Aromatic Separation Process

The capability of proposed methodology is tested in designing sustainable energy distillation column sequence for aromatic mixture separation process. The objective of the aromatic mixture separation process is to recover individual fractions using a distillation columns. In this paper, we assumed that the existing aromatic mixture separation process consists of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, o-xylene, m-xylene) with five direct sequence distillation columns. The feed composition, temperature and pressure are described in Table 1. In addition, the economic analysis is done in terms of rate of return on investment (ROI). In order to analyse the economic performance, the operating and modification costs must be calculated as well as the sustainability to show the differences between research study in this paper and the driving force approach [1].

Table 2. Feed conditions of the mixture

1. ***Components***	2. ***Mole Fractions***	3. ***Temperature (° C)***	4. ***Pressure (atm)***
5. Methylcyclopentane (MCP)	6. 0.1		
9. Benzene	10. 0.1		
1. Methylcyclohexane (MCH)	12. 0.1	7. 30	8. 2
13. Toluene	14. 0.1		
15. *o*-Xylene	16. 0.1		
m-Xylene	17. 0.5		

3.1 Existing Sequence Sustainability Analysis

Figure 1 illustrates the existing separation sequence which is the direct sequence of the aromatic mixture separation process. The existing aromatic mixture separation process was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 20.07 MW energy used to achieve 99.9% of product recovery. From the results, the calculated sustainability index is 848.71 obtained from the sustainability evaluator.

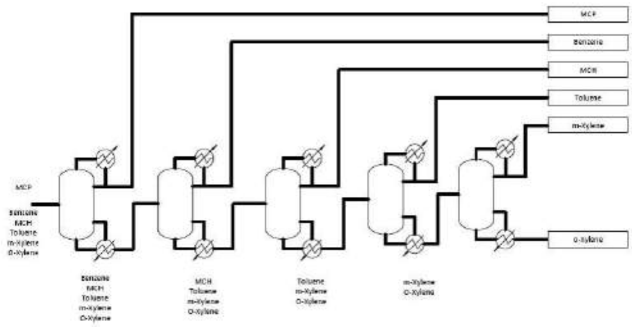

Figure 1 Existing Separation Sequence (Direct Sequence) of Aromatics Separation Process

3.2 Optimal Sequence Determination

The optimal sequence of aromatic mixtures was determined by using driving force method. All individual driving force curves was plotted as shown in the Figure 2, and the optimal sequence was determined based on the plotted driving force curves. The new sequence based on driving force is shown in the Figure 3.

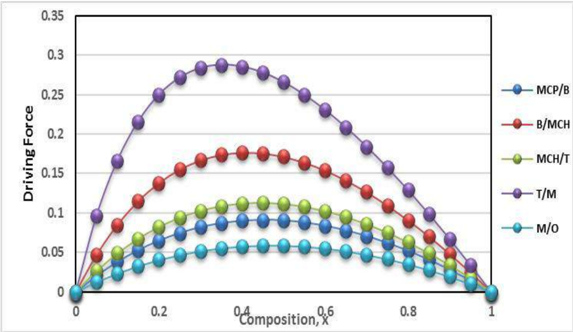

Figure 2 Driving Force Curve for set of binary component at uniform pressure

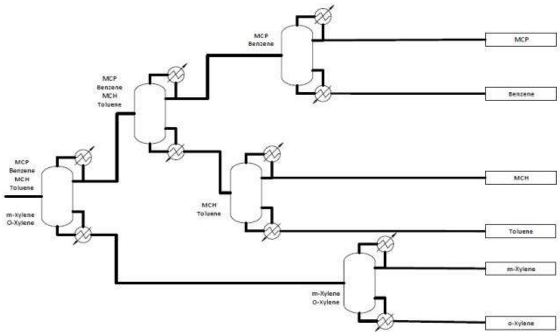

Figure 3 Simplified flow sheet illustrating the optimal Driving Force sequence of Aromatic mixture separation process.

3.3 Optimal Sequence Sustainability Analysis

A new optimal sequence determined by driving force method (see Figure 3) was simulated using a short-cut method within Aspen HYSYS environment where a total of 18.71 MW of energy was used for the same product recovery. The calculated sustainability index obtained from the sustainability calculator is 847.35 based on the energy analysis.

3.4 Sustainable Comparison and Economic Analysis

Sustainability index for the recovery of the aromatic mixture for the existing direct sequence and the new optimal sequence determined by the driving force method is calculated and the results show that 0.16 % sustainability reduction was able to achieve by changing the sequence suggested by the driving force method. The economic analysis is carried out by considering the cost of modifying the direct sequence distillation unit arrangement into that of the driving force, the cost of re-piping works as the capital cost and the reduction in condenser and reboiler duty as the net earnings. In order to evaluate the economic analysis, the length of pipes needed for re-piping works is estimated by comparing the original sequence with the modified one Based on calculation regarding the economic analysis, the return of investment (ROI) generated with amount of 3.10. The repiping cost will take almost USD$ 160,000 with the payback period for the modification of the process from direct method into the driving force method is about 0.32 year or approximately 4 months.

4 Conclusion

The study and analysis of the energy saving and sustainability 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 with 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 0.16 % sustainability index reduction was able to achieve by changing the sequence suggested by the driving force method. In addition, this typical methodology can be used in other separation sequences or different chemical product which involve the distillation process in future research and case studies. 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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