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Hydrocarbon Mixture Fractionation Direct Sequence Retrofitting and Feed Condition Sensitivity Analysis

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The objective of this paper is to present the retrofit analysis for the hydrocarbon mixture (HM) direct sequence fractionation process and to analyse the process sensitivity with respect to feed conditions. To perform the study and analysis, the energy efficient HM separation process methodology has been developed. The methodology consists of four hierarchical steps. In the Step 1, a simple and reliable short-cut method of process simulator (Aspen HYSYS) is used to simulate a direct HM sequence. The energy used to recover individual fractions in the base sequence is analysed and taken as a reference. In the Step 2, an optimal HM sequence is determined 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. Once the optimal HM sequence has been determined, the new optimal sequence is then simulated in Step 3 using a simple and reliable short-cut method (using Aspen HYSYS), where the process sensitivity and energy used in the optimal HM sequence are analysed, the process sensitivity of optimal HM sequence is compared with the other three different sequences by changing their feed conditions. Better sensitivity sequence was achieved when compared optimal sequence with the other three sequences in Step 4, the sequence determined by the driving force method has better sensitivity compared to the three other sequences as well as less energy requirement. All of these findings show that the methodology is able to design better sensitivity and minimum energy distillation column sequence for HM fractionation process in an easy, practical and systematic manner.

1. Introduction

The distillation process is utilised to recover 95 % of all fluid separations in the chemical industry and accounts for 3 % of global energy consumption (Hernández et al., 2005). This large energy consumption will increase the operating cost as energy costs are raising due to the increase in crude oil prices. It is also a known fact that large energy consumption contributes to large amount of carbon dioxide (CO_2) emissions due to the burning of fossil fuels. In an industry, 70 % of operation costs are due to energy expenses in which 19 % is from distillation (Schaller, 2001). Distillation is the most essential method used for separation, there is a major drawback that is the high-energy consumption.

Despite its many well-known advantages and widespread use, the issue of energy consumption by distillation column has received considerable critical attention among researchers due to its significant energy requirements (Long and Lee, 2011). Pejpichestakul and Siemanond (2013) stated that this highly energy consuming unit shows opportunities for energy saving. Optimisation and pinch analysis are one of the methods that can be applied to save the energy consumption by distillation system (Kamel et al., 2013). Despite intensive research, a closed solution for identifying the most energy efficient separation sequences for a given separation task is still elusive.

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No previous study has investigated the method to design the energy efficient distillation column sequences with a minimum cost or without involving major modification in the separation units, minimal cost expenses, better sensitivity and maximum energy saving. This paper focuses on the study and analysis of the energy saving improvement for the hydrocarbon mixtures separation process using the driving force method without having any major modifications to the major separation units. There will be only modifications to the separation sequences based on the driving force results, which significantly reduces the energy requirement.

The concept of the driving force was introduced to the distillation process by Bek-Pederson and Gani (2004) for improving the energy efficiency. Previous studies have applied this method (Zaine et al., 2015). The concept has been applied by Mustafa et al. (2015) in designing the optimal sequence with the most energy efficient. Accordingly, the first column should be the one with the largest value of the maximum driving force. The largest value of the maximum driving force means the easiest separation task with the minimum energy requirement, the lowest value of the maximum driving force means the most difficult separation task with the maximum energy requirement, which should be the last column in the sequence. This is because the driving force is inversely proportional to the energy added to the system to create and maintain the two-phase (vapour-liquid) system.

The objective of this paper is to present the retrofit analysis for the hydrocarbon mixture (HM) direct sequence fractionation process and to analyse the process sensitivity with respect to feed conditions. To perform the study and analysis, the energy efficient HM separation process methodology has been developed. The methodology consists of four hierarchical steps. More details on this will be given in the next section. Several case studies involving several sequences have been used to test the performance of the developed methodology, the findings are discussed and summarised.

2. Methodology

In this section, the methodology for designing the best sequence that will have better sensitivity and less energy requirement in hydrocarbon mixtures distillation columns are discussed.

2.1 Methodology for finding the best hydrocarbon mixtures distillation columns sequence

This section discusses in general the methodology in finding the best Hydrocarbon Mixtures (HMs) distillation columns sequence which have better sensitivity and use less energy than the existing sequence, the methodology consists of four hierarchical steps (see Figure 1).

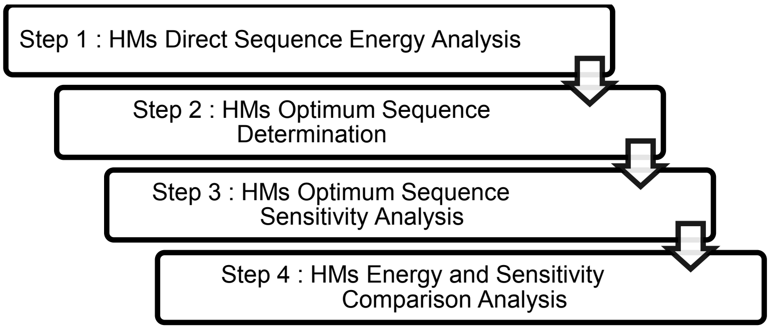

Figure 1: Methodology in finding the best hydrocarbon mixtures distillation column sequence

The first step deals with the direct sequence energy analysis, which will become the base sequence used for verification purposes. In this step, the direct sequence for HMs is simulated and the energy used is analysed using a simple and reliable shortcut method distillation column in Aspen HYSYS environment. Then in the second step, the optimum sequence was determined using driving force method to improve the energy efficiency of the distillation column. All individual driving force curves for all adjacent components are plotted and the optimal sequence is determined based on the plotted driving force curves. According to Bek-Pederson and Gani (2004), at the highest value of the maximum driving force, separation becomes easier and the energy required maintaining the separation is at the minimum. In the third step, the optimum sequence is analysed in term of energy and sensitivity analysis by using a simple and reliable shortcut method distillation column in Aspen HYSYS environment. In this step, another three sequences which are indirect, splitter 1 and splitter 2 sequences were developed. The feed conditions such as pressure, temperature and flowrate will be changed to analyse the sensitivity of all sequences. Finally, the energy and sensitivity analysis between each sequence are compared in the fourth step.

3. Result and discussion

3.1 Direct sequence

Figure 2 illustrates the existing separation sequence of the HM fractionation process. The feed composition, temperature and pressure are described in Table 1. The existing HM fractionation process was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 232,079.85 kW energy was used to achieve 99.9 % of product recovery.

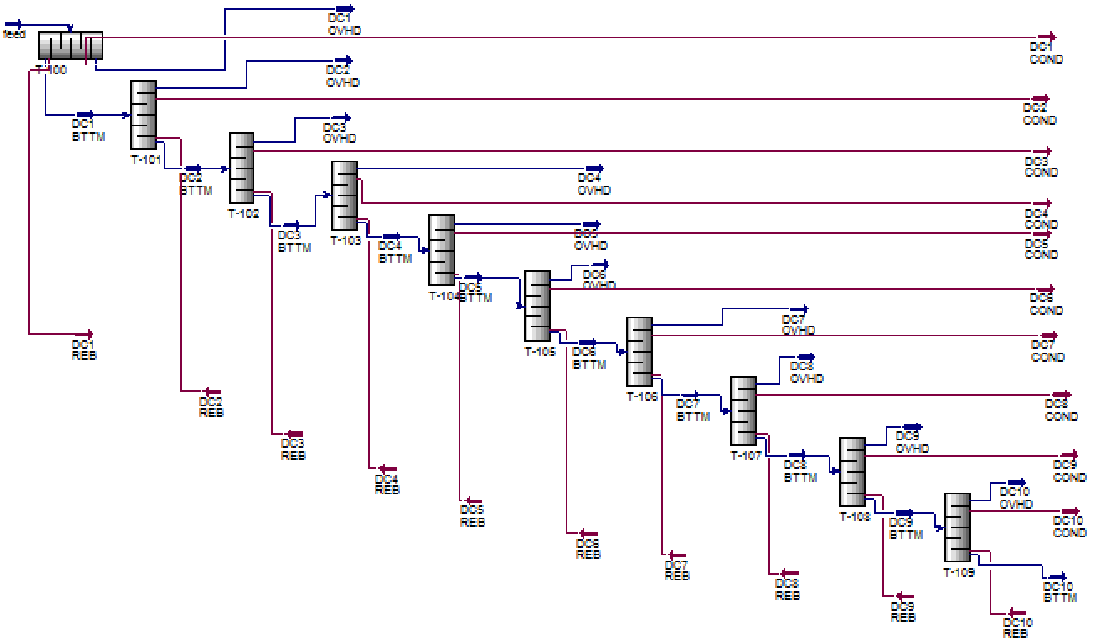

Figure 2: Simplified flow sheet illustrating the direct sequence of HM separation process for case study 1

Table 1: Feed conditions of the hydrocarbon mixtures

Feed conditions		
Component	Molar flow (kmol/h)	Mole fractions (%)
Propane	30.35	0.057
i-Butane	18.64	0.035
n-Butane	51.44	0.092
i-Pentane	27.67	0.067
n-Pentane	35.70	0.052
Benzene	44.72	0.084
n-Hexane	13.29	0.025
Cyclohexane	20.77	0.039
n-Heptane	59.10	0.111
Toluene	87.32	0.164
n-Decane	145.9	0.274
Temperature	172.4 °C	
Pressure	14.79 bar	

3.2 Optimal sequence

The optimal HM sequence was determined using driving force method. All individual driving force curves was plotted as shown in the Figure 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 Figure 4.

A new optimal sequence determined by driving force method (Figure 4) was simulated using a short-cut method within Aspen HYSYS environment where a total of 141,957.93 kW of energy was used for the same product recovery.

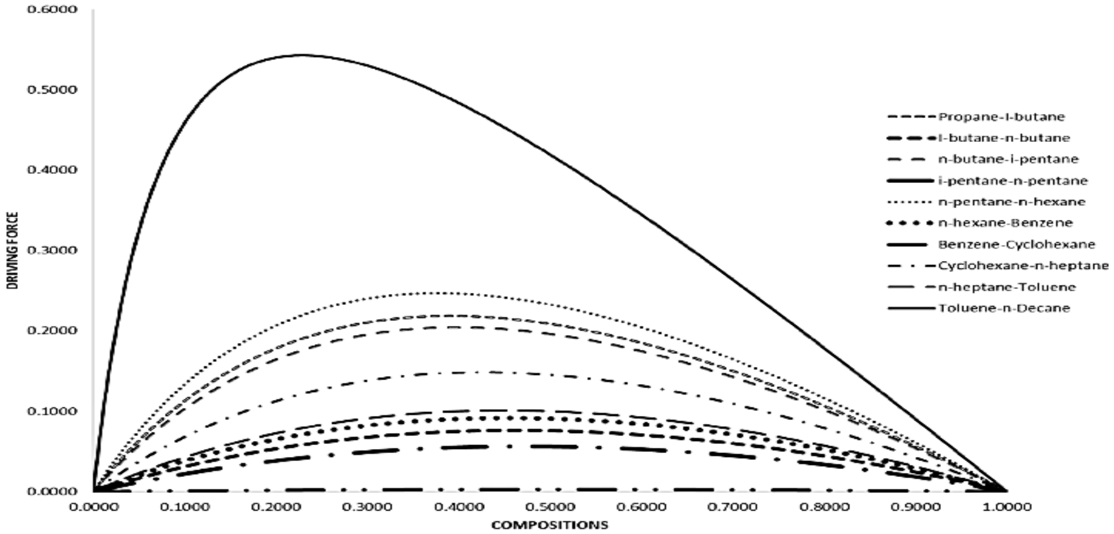

Figure 3: Driving Force curves for set of binary component at uniform pressure

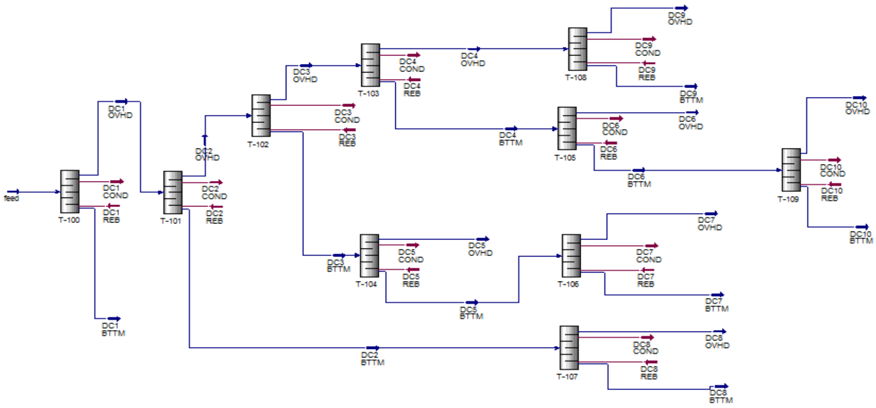

Figure 4: Simplified flow sheet illustrating the optimal driving force sequence of HM fractionation process case study 2

3.3 Indirect sequence

Figure 5 illustrates the indirect separation sequence of the HM fractionation process. The feed composition, temperature and pressure are the same as described in Table 1. The existing HM fractionation process was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 152,248.57 kW energy is being used to achieve 99.9 % of product recovery.

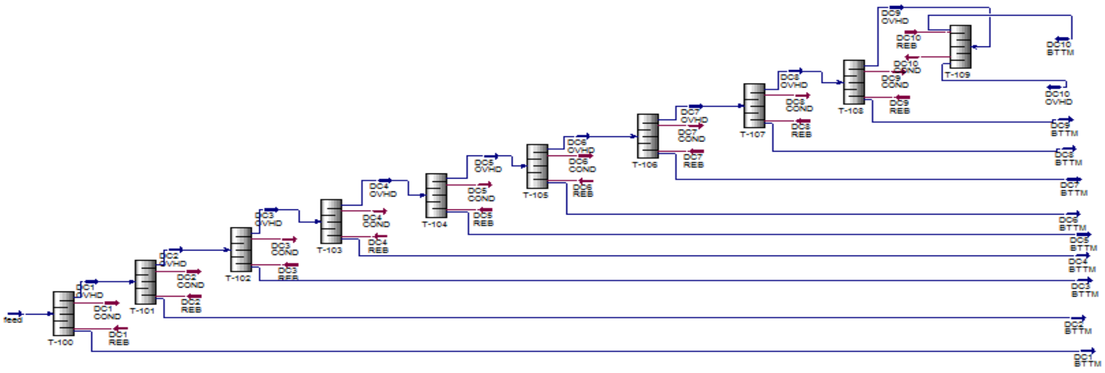

Figure 5: Simplified flow sheet illustrating the indirect sequence of HM fractionation process for case study 3

3.4 Splitter 1 sequence

Figure 6 illustrates splitter 1 separation sequence of the HM fractionation process. The feed composition, temperature and pressure are the same as described in Table 1. The splitter 1 sequence HM fractionation process was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 238,708.11 kW energy used to achieve 99.9 % of product recovery.

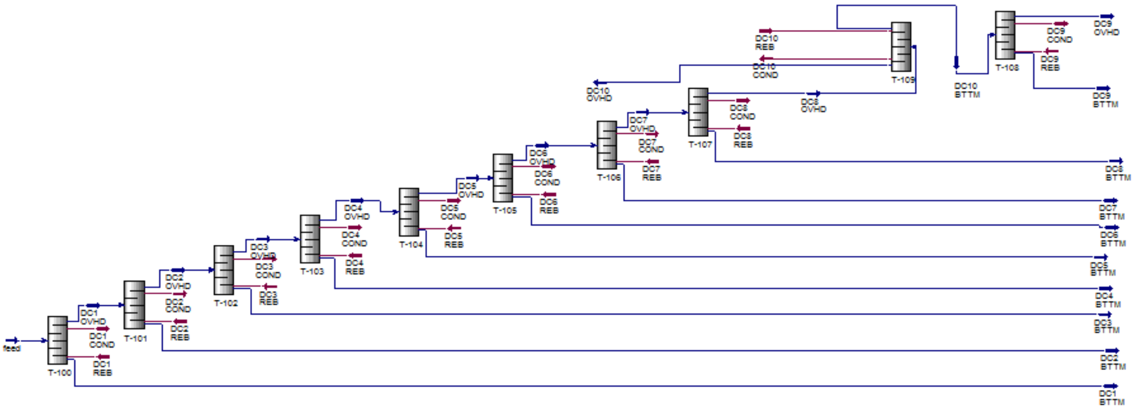

Figure 6: Simplified flow sheet illustrating the splitter 1 sequence of HM fractionation process for case study 4

3.5 Splitter 2 sequence

Figure 7 illustrates splitter 2 separation sequence of the HM fractionation process. The feed composition, temperature and pressure are the same as described in Table 1. The splitter 2 sequence HM fractionation process was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 154,063.49 kW energy used to achieve the same product recovery.

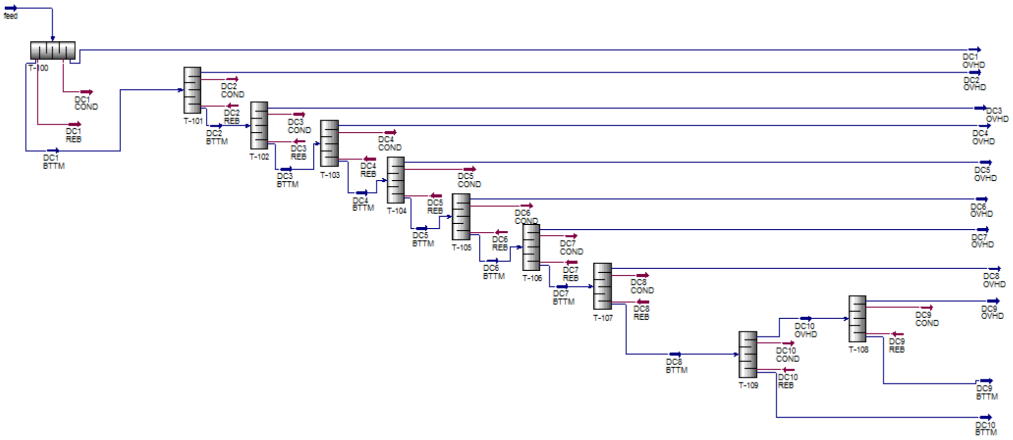

Figure 7: Simplified flow sheet illustrating the splitter 2 sequence of HM fractionation process for case study 5

3.6 Energy analysis

The direct sequence, along with four other sequences (optimal, indirect, splitter 1 and splitter 2), were analysed in terms of energy to determine the sequence with the least energy consumption. Each sequence was simulated in Aspen HYSYS simulation environment and the condenser and the reboiler duties were extracted from HYSYS' calculations. Energy analysis was done by comparing the energy used for every sequence. Table 2 provides the total energy consumption for each sequence.

3.7 Sensitivity Analysis

In order to analyse the sequences process sensitivity, the changes of energy consumption were measured based on the original energy consumption. The energy data collected from each feed conditions were compared with the original energy consumption. The energy changes were then divided by their respective disturbance changes to obtain the sensitivity of the sequences. It can be seen in from Table 3 that the driving force sequence has the best sensitivity compared to the other sequences. The driving force sequence evidently has better sensitivity in terms of feed conditions change. The results of this study found that driving force sequence is more robust in maintaining its controlled variables (in this case is energy requirement) in the presence of disturbance than other sequences.

Table 2: Energy comparison for Hydrocarbon Mixture separation process with original feed condition with respect to feed flow, temperature and pressure disturbance

Sequences	Total energy consumed (kW)	Energy saving (%)
Direct	232,079.85	
Optimal	141,957.93	38.8
Indirect	152,248.57	34.4
Splitter 1	238,708.11	-2.9
Splitter 2	154,063.49	33.6

Table 3: Average sensitivity for the sequences

Sensitivity of each sequence	Optimal	Indirect	Splitter 1	Splitter 2
Sensitivity	97.98	102.15	130.90	102.24

4. Conclusion

The main goal of the current study is to retrofit the hydrocarbon mixture direct sequence and to analyse sensitivity with respect to feed temperature, pressure and flow rate. These findings suggest that the optimal sequence has better average sensitivity compared to the other sequence. The present study offers clear evidence that driving force sequence has better sensitivity and able to reduce energy used for HM fractionation process, thus this methodology is able to design better sensitivity and minimum energy distillation column sequence for HM fractionation process in an easy, practical and systematic manner.

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