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ENERGY EFFICIENT DISTILLATION COLUMNS SEQUENCE FOR HYDROCARBON MIXTURES FRACTIONATION PROCESS

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Abstract. The objective of this paper is to present the study and analysis of the energy saving improvement for the hydrocarbon mixtures (HM) fractionation process by using driving force method. To perform the study and analysis, the energy efficient HM fractionation plant methodology is developed. Accordingly, the methodology consists of four hierarchical steps; step 1: existing HM sequence energy analysis, step 2: optimal HM sequence determination, step 3: optimal HM sequence energy analysis, and step 4: energy comparison and economic analysis. In the first step, a simple and reliable short-cut method of process simulator (Aspen HYSYS) is used to simulate a base (existing) HM 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 HM 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. Once the optimal HM 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 HM sequence is analyzed. Finally, the energy used in the optimal HMs sequence is compared with the base sequence. The return of investment (ROI) and simple payback period are also calculated. Several case studies have been used to test the performance of the developed methodology. The results show that a maximum energy saving of 40% was achieved when compared the optimal (driving force) sequence with the existing direct sequence. The ROI of 3 was obtained with 4 month of payback period. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for HM fractionation process. Individual column energy has also been analyzed, and from that several columns that can be improved in terms of energy saving have been identified. All of this findings show that the methodology is able to design minimum energy distillation column sequence for HM fractionation process in an easy, practical and systematic manner.

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

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1.0 INTRODUCTION

Distillation processes were recognized from the second millennium BC by Babylonian alchemists, but the first exact explanation of distillation apparatus was given in the fourth century by Zosimus of Alexandria [1].The distillation process is utilized to recover 95% of all fluid separations in the chemical industry and accounts for 3% of global energy consumption [2]. This large energy consumption will increase the operating cost as energy costs are raising due to the decrease in crude oil prices. It is also a known fact that large energy consumption contributes to large amount of carbon dioxide (CO2) emissions due to the burning of fossil fuels. Schaller et.al [3] stated that in an industry, 70% of operation costs are due to energy expenses in which 19 % is from distillation.

The energy efficient of distillation columns sequence becomes an important criterion during retrofitting and design of industrial chemical processes. The reason is because there is a major drawback that is the high energy consumption. The initial consideration when dealing with distillation sequence design is the possible sequence involves that corresponding to products recovery. The possible sequence involves can be determine by implement an equation developed by Seider, Seader and Lewin [4]. In order to improve the energy efficiency, there are several researches contributed to full-filled the demand. For example, Heaven [5] was one of the first that published a work introducing four general heuristic rules. In 1977 Seader and Westerberg [6] utilized the experience of other authors to collect the following list of revised heuristic rules. They include conditions for a generic separation method together with indications about the technical feasibility of ordinary distillation. When application of the heuristics for sequencing ordinary columns is uncertain or conflicting results obtained, Marginal Vapor Rate method [7] is used to perform analysis for each columns and possible sequences in order to find optimal sequence.

All above of this methods possessed of complexity to design optimal sequence of energy efficient distillation column. The concept of the driving force was introduced to the distillation process by Bek-Pederson and Gani [8]. According to Bek-Pederson and Gani [8], the optimal sequence with the most energy efficient can be determined from the plotted driving force curves. The first column should be the one with the largest value of the maximum driving force. Theoretically, the largest value of the maximum driving force means the easiest separation task with the minimum energy requirement. In addition, 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. However, these researchers only cover for simplest hydrocarbon fractionation process which involves three components of hydrocarbon.

This paper presents a systematic methodology energy efficient distillation columns sequence for hydrocarbon mixtures fractionation process. In the next section, a detail of the methodology which consists of four hierarchical steps is discussed. The application of the proposed methodology is tested by using complex hydrocarbon mixture separation sequence in section 3. The paper ends with the conclusion and future work

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2.0 METHODOLOGY

To perform the study and analysis of the energy saving improvement for the energy efficient HM fractionation plant sequence, energy efficient distillation columns (EEDCs) sequence methodology is developed based on the driving force method.

2.1 The Methodology Development in Finding the Best Hydrocarbon Mixtures Distillation Columns Sequence.

Accordingly, the methodology consists of four hierarchical steps as shown in Figure 1. In the first step, a simple and reliable short-cut method of process simulator (Aspen HYSYS) is used to simulate a base (existing) HM sequence. The energy used to recover individual fractions of the NGLs in the base sequence is analyzed and taken as a reference. In the second stage, an optimal HM 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. According to Bek-Pederson and Gani, the optimal sequence with the most energy efficient can be determined from the plotted driving force curves [8]. The first column should be the one with the largest value of the maximum driving force. Theoretically, the largest value of the maximum driving force means the easiest separation task with the minimum energy requirement. In addition, 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. 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.

Step 1 HM Existing Sequence Energy Analysis
Step 2 HM Optimal Sequence Determination
Step 3 HM Optimal Sequence Energy Analysis
Step 4 HM Existing Sequence Energy Comparison and Economic Analysis

Figure 1 Methodology in finding the best Hydrocarbon Mixtures distillation column sequence

3.0 RESULTS AND DISCUSSION

3.1 Energy Efficient Distillation Columns Sequence

The capability of proposed methodology is tested in designing minimum energy distillation column sequence for HM fractionation process. The objective of the HM fractionation process is to recover individual fractions of HM by using distillation columns. HM normally have significantly greater value as separate marketable products that as part of the crude oil stream. The HM fractionation process consists of eleven compounds (propane, i-butane, n-butane, i-pentane, n-pentane, n-hexane, n-heptane, benzene, toluene, cyclohexane, n-decane) with ten direct sequence distillation columns as an existing sequence.

Step 1: Existing Sequence Energy Analysis

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 249.09 MW energies used to achieve 99.9% of product recovery.

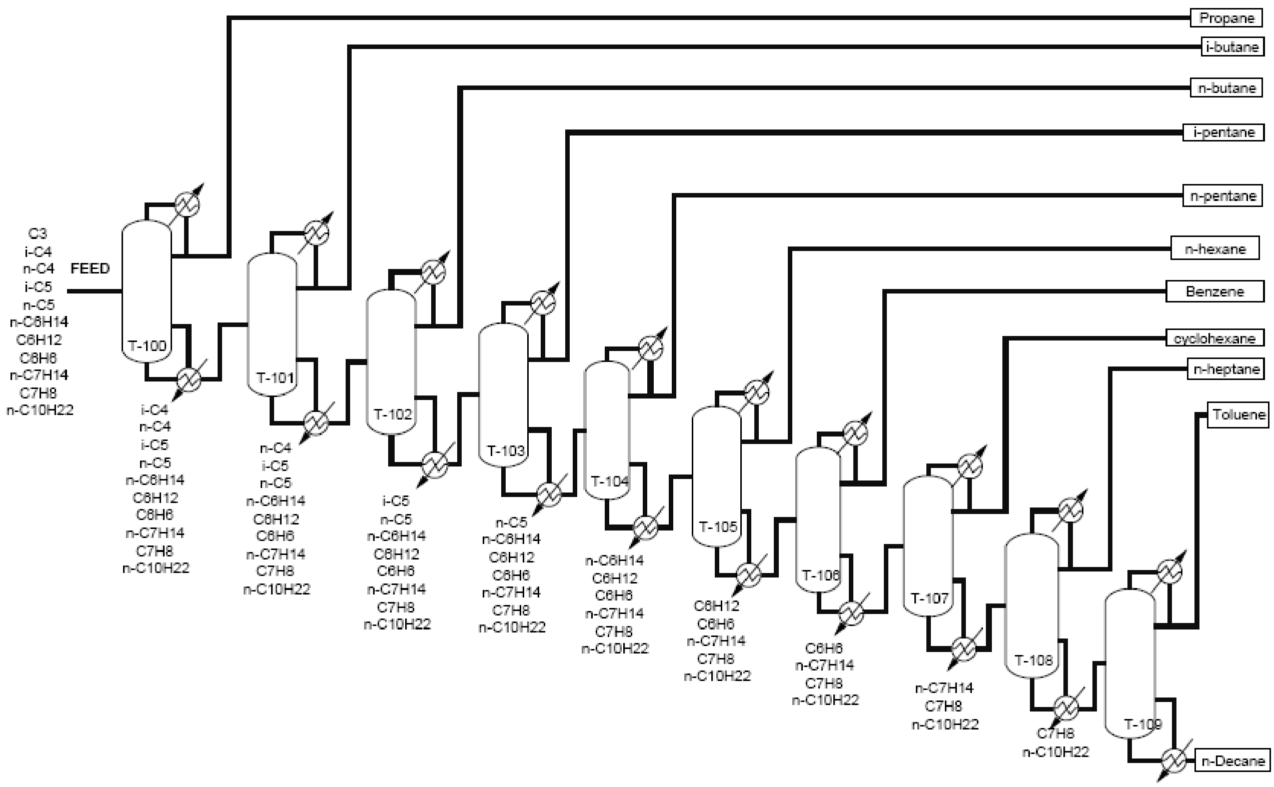

Figure 2 Simplified flow sheet illustrating the existing direct sequence of HM fractionation process.

Step 2: Optimal Sequence Determination

The optimal HM sequence was determined by 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.

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Table 1 Feed conditions of the mixture

Feed conditions		
Components	Mass flow (kg/h)	Mole fractions (%)
Methane	991.66	0.86
Ethane	87179.69	40.45
Propane	87268.17	27.61
i-Butane	26803.59	6.43
n-Butane	57180.35	13.72
i-Pentane	20649.83	3.99
n-Pentane	14600.65	2.82
n-Hexane	17559.16	2.84
n-Heptane	9099.56	1.27
Temperature (°C)	55.83	
Pressure (bar)	31.37	

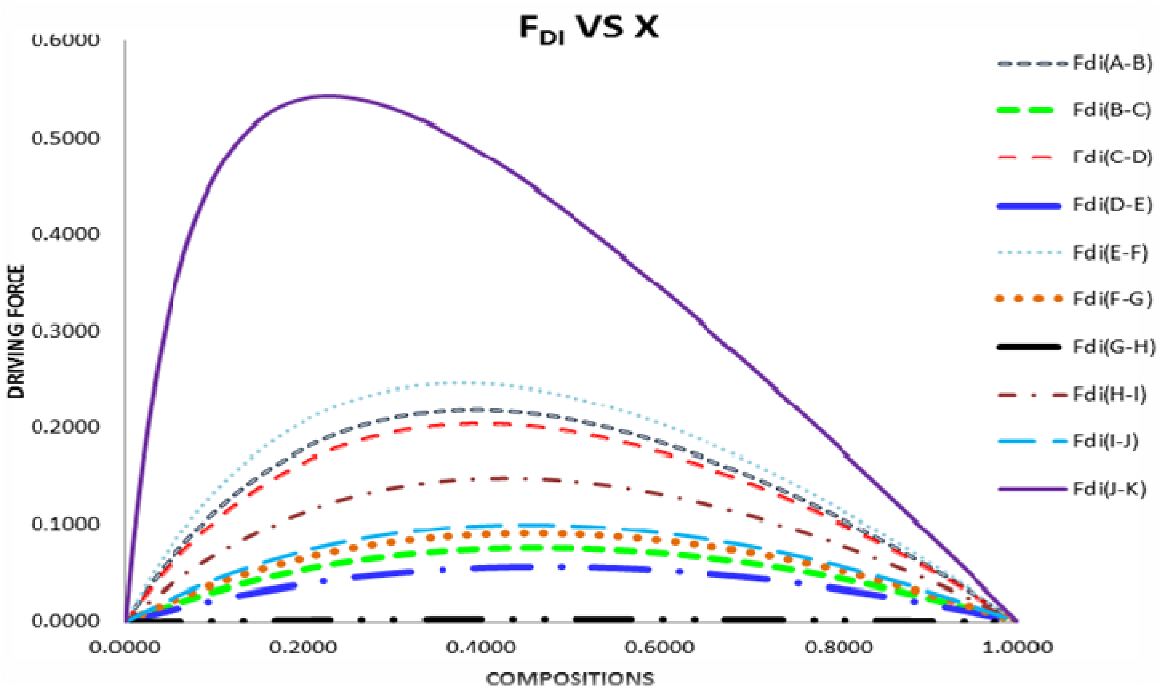

Figure 3. Driving Force curves for set of binary component at uniform pressure.

Step 3: Optimal Sequence Energy Analysis

Total energy used to recover every single HM 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 40 % energy reduction was able to achieve by changing the sequence suggested by the driving force method.

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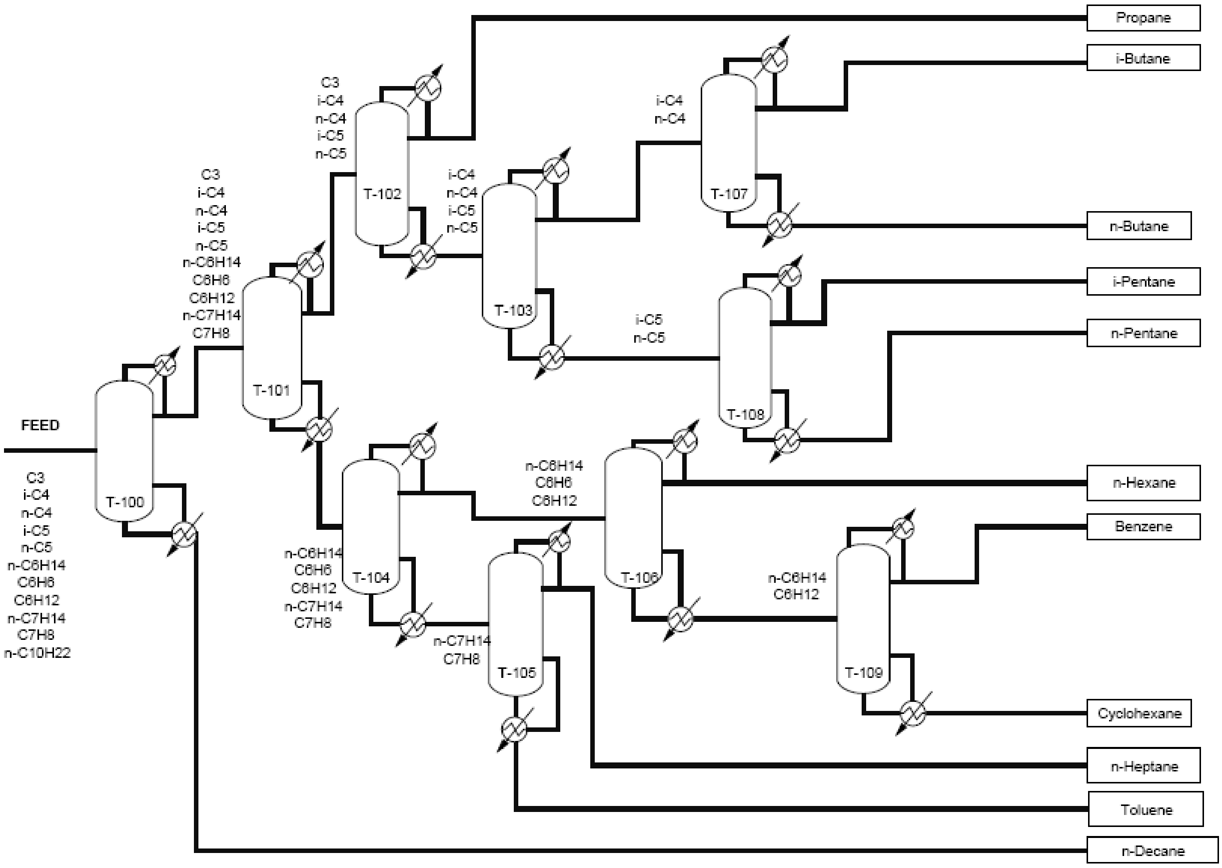

Figure 4 Simplified flow sheet illustrating the optimal Driving Force sequence of HM fractionation process

Table 2 Energy comparison for direct sequence and driving force sequence for HM fractionation process

Energy (MW)	Direct Sequence	Driving Force Sequence	Percentage (%)
Condenser	108.89	68.07	**37.49**
Reboiler	140.20	82.56	**37.49**
Total Energy	**249.09**	**150.63**	**39.53**

3.2 Economic Analysis

The results show that $260,816/year and $4,780,566/year saving of utilities were able to achieve for condenser and reboiler duties, respectively by changing the sequence suggested by the driving force method. The utility used for condenser and reboiler were cooling water and natural gas, respectively. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for HM fractionation process

In order to calculate the ROI and PBP, the cost of total initial investment need to calculate first. The calculation of initial investment is calculated based on updated MS index of 1365 with 514 purchase cost MS index in 2006. Table 3 illustrates the data of initial investment for modification as well as energy saving cost. The total cost for re-piping cost (modification) is based on Genereaux [9].

Table 3 Return on Investment (ROI) and Payback Period (PBP) for the re-piping modification of the existing sequence

Economic Aspects	**Cost ($/yr)**
Total Energy Saving	5,041,382
Total initial Investment (Modification)	1,675,962
Return on Investment (ROI)	3
Payback Period (PBP)	0.33 ≅ 4 month

The results show that ROI of 3 was obtained with 4 month of payback period.

3.3 Individual Column Energy Analysis

Table 4 illustrates the individual columns that has significant energy savings and the individual columns that needs the extensive improvement in terms of energy saving. By changing the sequence suggested by driving force method, seven columns of existing direct sequence indicate significantly of energy saving. However, columns which correspond to the splitting of Toluene/n-Decane, n-Pentane/n-Hexane and Benzene/Cyclohexane need the extensive improvement in terms of energy saving.

Table 4 Individual Column Energy Comparison

Column Unit	Sequence Total Duty (MW)		Percentage (%)
	Direct	Driving Force	
Toluene/n-Decane	12.71	32.80	-158.06
n-Pentane/n-Hexane	8.85	10.39	-17.40
Propane/i-Butane	13.14	2.86	78.23
n-Butane/i-Pentane	8.33	5.21	37.45
Cyclohexane/n-Heptane	25.57	20.52	19.75
n-Heptane/Toluene	56.04	20.82	62.85
n-Hexane/Benzene	39.55	14.19	64.12
i-Butane/n-Butane	12.64	7.36	41.77
i-Pentane/n-Pentane	28.59	14.80	48.23
Benzene/Cyclohexane	12.71	21.68	-70.57
Total	249.09	150.63	39.53

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4.0 CONCLUSION

Energy efficient distillation columns methodology for hydrocarbon mixture separation process using driving force method has been successfully developed. The results show that a maximum energy saving of 40 % was able to achieve when compared the optimal (driving force) sequence with the existing direct sequence. The ROI of 3 was obtained with 4 month of payback period. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for HM fractionation process. Individual column energy has also been analyzed, and from that several columns that can be improved in terms of energy saving have been identified. All of this findings show that the methodology is able to design minimum energy distillation column sequence for HM fractionation process in an easy, practical and systematic manner. For future work, energy saving of distillation columns can be further improved by modification of the distillation column configuration such as by using Petlyuk configuration or dividing wall column configuration [2].

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