Jurnal
Teknologi

Full Paper

Energy Efficiency Improvement for Natural Gas Liquids Direct-Splitter-Direct Sequence Fractionation Unit

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Article history
Received
1 February 2015
Received in revised form
24 March 2015
Accepted
1 August 2015

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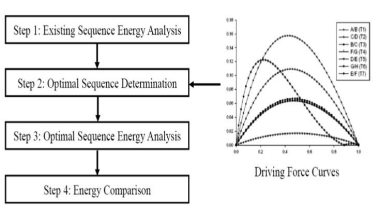
Graphical abstract



Abstract

The objective of this paper is to present the study and analysis of the energy saving improvement for the NGLs Direct-Splitter-Direct fractionation sequence plant by using driving force method. To perform the study and analysis, the energy efficient distillation columns (EEDCs) methodology is developed. Basically, 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 an optimal energy efficient direct-splitter-direct sequence of NGLs fractionation unit. The results show that the maximum of 10.62 % 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 a NGLs fractionation. All of this findings show that the methodology is able to design energy efficient for NGLs fractionation sequence in an easy, practical and systematic manner.

Keywords: Energy Efficient, Distillation Columns Sequence, Driving Force, Natural Gas Liquid

1.0 INTRODUCTION

The distillation process is utilized to recover 95 % of all fluid separations in the chemical industry and accounts for 3 % of global energy consumption [1]. Based on the Department of Energy United States of America (USA), about more than 40,000 distillation columns in North America and they consumed about 40 % of the total energy used to operate plants in the refining and bulk chemical industries [2]. Thus, a major problem with this kind of application is that its large energy consumption will increase the operating cost. This becomes the reason why the plant designer must take the different energy saving solutions into consideration and choose the best distillation columns systems design for the specific separation task.

A large number of researches have been conducted to focus 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 [3]. Distillation continues to be the most significant separation technique not only for non-ideal mixtures but also for azeotropic mixtures even on the negative side that is quite expensive operation in terms of capital and operating costs [4]. There is lots of a general review of distillation synthesis [5 – 8]. Superstructure optimization [9], graphical method [10], heuristic methods [11] and evolutionary techniques [12] are several approaches to design efficient separation systems.

The heuristic method will help to determine more economical sequences without requires a column design and also cost. There are various reviews of synthesis of distillation sequence by heuristics [13 – 15]. Several steps through heuristics are: (1) Thermally unstable, corrosive or chemically reactive components is removed early in the sequence, (2) Final products is removed one-by-one as distillates (the direct sequence), (3) Sequence separation points to remove, early in the sequence, those components of greatest molar percentage in the feed, (4) Separation points is sequenced in the order of decreasing relative volatility so that the most difficult splits are made in the absence of other components, (5) Separation points is sequenced to leave last those separations that give the highest purity products, (6) Separation points that favor near equimolar amounts of distillate and bottoms in each column is sequenced [16]. Heuristic methods are potentially uncertain or conflicting results may be obtained, thus, it is preferable to employ sequencing methods that rely on column design and, in some cases, cost estimation. In this method, analysis should be done for each columns and possible sequences in order to find the optimal sequence [17].

Due to practical constraints of previous method, optimization methods can be used to find efficient distillation sequence [18 – 19]. In this method, all possible configurations of separation tasks will be embedded through superstructure which is used to extract the desired sequence by a nonlinear programming problem [18]. To produce multicomponent products from a single multicomponent feed through minimum number of columns using a nonsharp separation sequence, a bounding procedure could be used [19]. But the disadvantages of this method are that it requires special mathematical background and computational skills from the user.

The graphical method can be categorized into several categories which are McCabe-Thiele, driving force and pinch technology which can be used to determine the optimal design of distillation columns sequence. To determine the design values of distillation column in a simple technique, the McCabe-Thiele has been proposed [20]. In distillation column, driving force is the difference between composition in vapor phase and liquid phase as a result of difference of properties such as boiling point and vapor pressure [21]. In this method, a pinch technology method is proposed which produces minimum energy usage as part of the energy monitoring [22].

Generally, driving force is applied in multicomponent systems that has varies physical or chemical properties between different phases will existing together. In distillation column, the driving force can be shown by facing distinction 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. In theoretical, 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. This is because the driving force is inversely proportional to the energy added to the system to create and maintain the two-phase. Through a systematic synthesis of energy integrated distillation column systems, external energy input can be reduced and as a result the heat exchange between the integrated columns is maximized [23].

No previous study has investigated the method to design the optimum distillation column sequences without involving major modification units at the minimum cost. The objective of this paper is to study and analyze the energy saving improvement for natural gas liquids separation processes 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 will reduce the energy requirement.

2.0 METHODOLOGY

To perform the study and analysis, the energy efficient NGLs fractionation sequence methodology is developed [24]. In this section, the step-by-step algorithm which consists of four stages for finding the best sequence in distillation columns design briefly mentioned in Figure 1 are discussed in more details.

2.1 Stage 1: Existing Sequence Energy Analysis

The objective of this stage is to analyze the energy requirement in the existing distillation columns sequence.

2.1.1 Step 1.1: Feed Information Gathering

The feed of the existing distillation columns sequence information such as temperature, pressure, flow rate and composition are gathered in this step.

2.2.2 Step 1.2: Existing Sequence Information

After collected all the feed information, the next step that should be considered is to determine the existing sequence configuration, for example direct or indirect sequence.

2.2.3 Step 1.3: Sequence Simulation Using Shortcut

In this step, the existing sequence is simulated and analyzed by using a simple and reliable shortcut method of distillation column design in Aspen HYSYS environment. The fluid package used in this simulation for the shortcut method is Peng-Robinson and the purity of the recovery of products is set to 99.9 %. The reflux ratio of the existing sequence is also needed for the simulation purposes.

2.2.4 Step 1.4: Energy Requirement

After the existing sequence has been simulated, the information in terms of utilities (cooling and heating requirements) are extracted. Then, the energy used to recover individual fractions in the existing sequence is analyzed and taken as a reference that will be used in stage 4 for comparison purposes.

2.2 Stage 2: Optimal Sequence Determination

The objective of this stage is to determine the best sequence that will be able to use less energy than the existing sequence. In this 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 of the binary pairs which will require data for Antoine equation. After that, the individual driving force curve graph is plotted according to these steps developed by Bek-Pederson and Gani [23].

2.2.1 Step 2.1: Component Listing According to the Boiling Point

All multicomponent compounds have to be listed according to their boiling points with the lightest to heaviest boiling point.

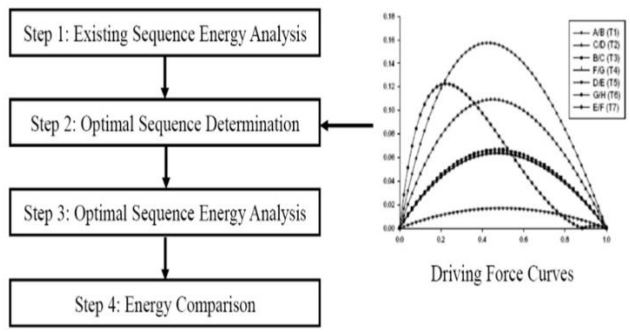


Figure 1 Energy efficient distillation columns sequence methodology [24]

2.2.2 Step 2.2: VLE Data Collected

The vapour-liquid equilibrium data for the multicomponent system in the column will be collected from a process simulator database according to the specified component.

2.2.3 Step 2.3: Define Split for Binary Mixture

In multicomponent system, two adjacent components will be selected to define the "split" and use as the binary mixture.

2.2.4 Step 2.4: Driving Force Curves Construction

The driving force (*FD*) between the two (key) components at the actual operating pressure will be calculated by using Eq. (1) and the graph of driving force as a function of the light key component can be plotted as shown in Figure 2. In the figure, *y*-axis represents the driving force value, *FD* that have been calculated by using given formula and the *x*-axis represents the liquid composition of the light component.

$$F_{ij} = y_i - x_i = \frac{x_i \beta_{ij}}{1 + x_i(\beta_{ij} - 1)} - x_i \quad (1)$$

As seen in the model equation above, the driving force is defined as the difference in composition. The terms x_i and y_i denote liquid and vapour phase compositions of *i*, and F_{ij} is the driving force for component *i* for property *j*. The relative separability β_{ij} is a parameter for component *i* with respect to property (or separation technique) *j*, which may or may not be composition-dependent and provides a measure of the driving force. Note that in Eq. (1), all the component indices are in principle with respect to the second component *k* (in the binary pair).

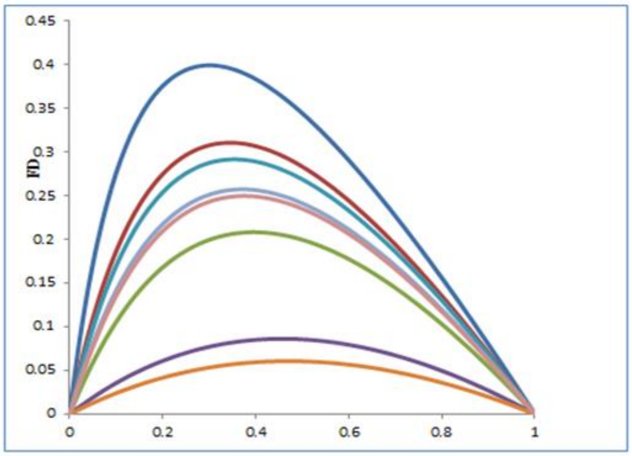


Figure 2 Driving force curves

2.2.5 Step 2.5: Sequence Determination Based on Driving Force Curves

The optimal sequence can be determined by the drawn curves shown in Figure 2. According to Bek-Pederson and Gani [1], 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.

2.3 Stage 3: Optimal Sequence Energy Analysis

The objective of this stage is to analyze the energy requirement of the optimal sequence. The feed composition, temperature and pressure are described as the same in stage 1.

2.3.1 Step 3.1: Shortcut Simulation for Optimum Sequence

Once the optimal sequence has been determined, the new optimal sequence is then simulated in this stage using a simple and reliable short-cut method of distillation column design (using Aspen HYSYS). The fluid package used in this simulation for the shortcut method is Peng-Robinson and the purity of the recovery of products is set to 99.9 %. The reflux ratio of the existing sequence is also needed for the simulation purposes.

2.3.2 Step 3.2: Energy Requirement

After the optimal sequence has been simulated, the information in terms of utilities (cooling and heating requirements) are extracted. Then, the energy used to recover individual fractions in the optimal sequence is analyzed and compared in the next stage.

2.4 Stage 4: Energy Comparison and Economic Analysis

The objective for this stage is to determine which sequence has the less energy by doing energy comparison between existing and optimal sequences. The second objective is to analyse the economic performance by measuring the return of investment (*ROI*) and payback period for the investment.

2.4.1 Step 4.1: Energy Comparison

The total energy from existing sequence and optimal sequence by driving force are compared in this stage.

2.4.2 Step 4.2: Energy Saving Calculation

From the energy analysis, the percentage energy reduce can be calculated and then converted into dollar.

3.0 RESULTS AND DISCUSSION

In this section, the existing direct-splitter-direct sequence of NGLs fractionation process as shown in Figure 3 is used to illustrate the capability of the proposed methodology.

3.1 Existing Sequence Energy Analysis

The feed composition, temperature and pressure of the existing direct-splitter-direct sequence of NGLs fractionation process are described in Table 1. The purity of the recovery products in NGLs mixture is set to 99.9 %. After the sequence has been simulated, the data in terms of utilities (cooling and heating requirements) is extracted. Then, the energy used to recover individual fractions of the NGLs mixtures in the existing sequence is analyzed and taken as a reference that will be used in the next step for comparison purposes. A total of 137.50 MW energy used to achieve 99.9 % of product recovery.

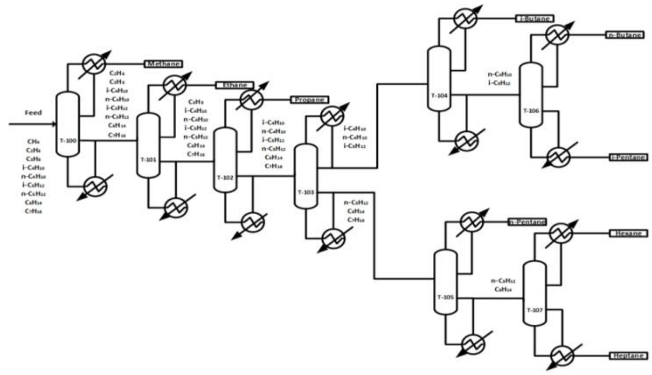


Figure 3 Flow sheet illustrating the existing direct-splitter-direct sequence of NGLs fractionation process

3.2 Optimal Sequence Determination

A new optimal sequence was determined by driving force method. The binary pairs are methane-ethane, ethane-propane, propane-isobutane, isobutene-butane, butane-isopentane, isopentane-pentane, pentane-hexane, and hexane-heptane, which requires data for Antoine equation. All individual driving force curves was plotted as shown in Figure 4, and the optimal sequence was determined based on the plotted driving force curves. The new optimal sequence based on the driving force method is shown in Figure 5. 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.

Table 1 Feed conditions of the NGLs mixture [25]

Component	Composition	Mass Flow (kg/hr)	Molar flow (kgmol/hr)
Methane	0.5952	47744	2976
Ethane	0.0536	8059	268
Propane	0.0471	10385	235.5
i-Butane	0.0203	5900	101.5
n-Butane	0.0239	6946	119.5
i-Pentane	0.0180	6494	90
n-Pentane	0.0161	5808	80.5
Hexane	0.0260	11203	130
Heptane	0.1998	100105	999
Total	1.0000	202642	5000
Temp. ($^{\circ}$C)		55.83	
Pressure (Bar)		31.37	

3.3 Optimal Sequence Energy Analysis

The objective of this step is to analyze the energy requirement of the optimal NGLs sequence. The feed composition, temperature and pressure are described as same in Table 1 Once the optimal sequence has been determined, the new optimal sequence is then simulated in this step using a simple and reliable short-cut method of distillation column (using Aspen HYSYS), where the energy used in the optimal sequence is analyzed (see Figure 5) where a total of 122.9 MW of energy was used of the same product recovery.

3.4 Energy Comparison

Total energy used to recover every single NGLs fractions for the existing sequence and the new optimal sequence determined by the driving force method is shown in Table 2. The results show that 10.62 % 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 NGLs fractionation process.

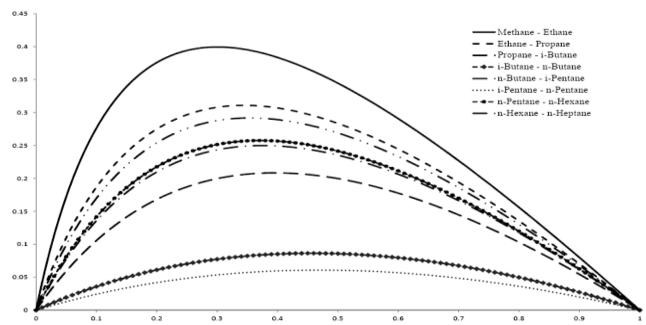


Figure 4 Driving force curve for set of binary component at uniform pressure

Table 2 Energy Comparison between Direct-Splitter-Direct sequence and Driving Force sequence for NGLs fractionation process

Distillation Column Unit	Direct-Splitter-Direct Sequence (MW)	Driving Force Sequence (MW)	Percentage Difference (%)
Total Condenser Duty (MW)	65.88	58.58	11.09
Total Reboiler Duty (MW)	71.62	64.32	10.19
Total Energy (MW)	137.50	122.9	10.62

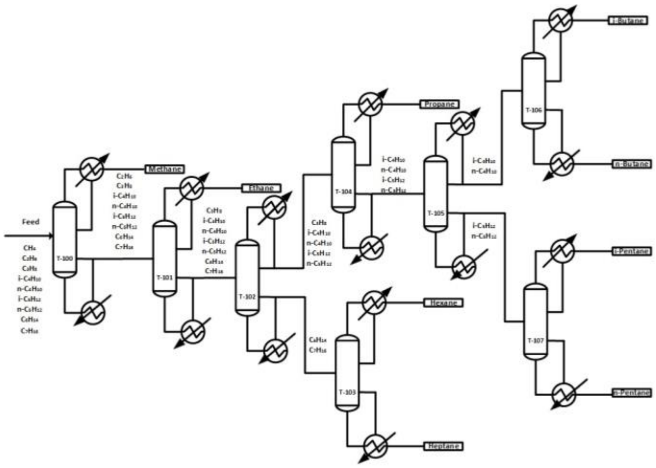


Figure 5 Flow sheet illustrating the existing direct-splitter-direct sequence of NGLs fractionation process using driving force method

4.0 CONCLUSION

Distillation columns are the primary separation process widely used in the industrial natural gas 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 greatly reduced by changing the sequence of the distillations columns. To perform the study and analysis, the energy efficient distillation columns (EEDCs) methodology has been developed. Basically, 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 an optimal energy efficient direct-splitter-direct sequence of NGLs fractionation unit. All of this findings show that the methodology is able to design energy efficient direct-splitter-direct for NGLs fractionation sequence in an easy, practical and systematic manner. The results show that the maximum of 10.62 % energy reduction was able to achieve by changing the sequence suggested by the driving force method.

Acknowledgement

The financial support from Universiti Teknologi Malaysia (RUGS Tier 1 Q.J130000.2509.07H39) and Ministry of Education of Malaysia FRGS (R.J130000.7809.4F435) are highly acknowledged.

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