

Optimal Retrofit of Natural Gas Liquids Separation Direct Sequence and Feed Condition Sensitivity Analysis

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The objective of this paper is to present the retrofitting analysis for the direct sequence natural gas liquids (NGLs) separation process and to analyse the process sensitivity with respect to feed conditions. To perform the study and analysis, the energy efficient NGLs separation process methodology is developed. Hence, the methodology consists of four hierarchical steps. In Step 1, a simple and reliable short-cut method for distillation column design of process simulator (Aspen HYSYS) is used to simulate a base (direct) NGLs sequence. The energy used to perform the separation is obtained that will be used for comparison purpose. In the Step 2, an optimal NGLs 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. The optimal sequence is then simulated in Step 3 using a simple and reliable short-cut method (using Aspen HYSYS), where the energy used in the optimal NGLs sequence is analysed. Finally, the energy and sensitivity used in the optimal NGLs sequence is compared with the base sequence in Step 4. Several case studies involving several sequences have been used to test the performance of the developed methodology. A maximum energy saving of 11.7 MW was achieved when compared with the optimal (driving force) sequence with the direct sequence. For sensitivity analysis, the results show that the driving force sequence has the best sensitivity compared to other sequences. These findings show that the developed methodology is not only able to design energy efficient distillation columns sequence but also better process sensitivity with respect to the feed conditions for NGLs separation process in an easy, practical and systematic manner.

1. Introduction

Separation by distillation plays an important role in many process industries including chemical, petrochemical, biochemical and bioenergy. 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 as well as it can significantly influence the overall plant profitability (Long and Lee, 2011). Matsuda et al. (2012) reported that the energy consumption by the distillation has a tendency to increase the greenhouse gas emissions, while Pejpichestakul and Siemanond (2013) stated that this highly energy consuming unit shows opportunities for energy saving.

The determination of feasible sequences of multiple distillation columns, whether on the basis of minimum overall energy consumption, total annualised costs, sustainability, or some other metric, has been the subject of academic and industrial investigation for many years. Quite a number of publications have been on ways to determine the best sequence form a given number of components feed mixture. Several methods can be used to determine the best sequence as follows (a) Heuristic methods based on rules of thumb, (b) Algorithmic approaches involving established optimisation principles (algorithmic methods) and (c) Graphical method.

Heuristics methods are becoming common methods for the process synthesis (Malone et. al., 1985). There are various reviews of synthesis distillation by heuristics which are conducted by other researchers (Tedder and Rudd, 1978). Some of the heuristic methods that can be used for distillation sequences are: (a) the lightest component is removed first, (b) the most plentiful is removed first, (c) difficult separations are saved until last and (d) equimolar splits are favoured. However, the problems of using this method are that the first and the third depend on relative volatility, whereas the second and fourth depend on feed composition. Thus, there is a need to find an alternative for this application as it is uncertain or conflicting results obtained.

Due to practical constraints, this method could be replaced with optimisation methods where it can be used to find efficient distillation sequence (Floudas, 1987) and also in the work of (Wehe and Westerberg, 1990). Optimisation method or is also known as algorithmic method can be used as an alternative to identify the best separation sequence even it requires computational time and huge effort. But the disadvantages of this method are that it requires special mathematical background and computational skills from the user.

The graphical method can be classified into several categories which are McCabe-Thiele, driving force and pinch technology which can be used to determine the optimal design of distillation columns. The McCabe-Thiele has been used as a basic and simple technique to determine the design values of distillation column (Wang and Mansoori, 1994). Meanwhile, pinch technology represent as a simple thermodynamically method that produce minimum energy consumption by using the first key of pinch analysis (setting energy target) as a key part for energy monitoring (Kemp, 2007). In addition, a systematic synthesis of energy integrated distillation column systems was proposed which enable to reduce external energy input of the distillation column systems (Sobocan and Glavic, 2002). Through this method the utility consumption is minimised meanwhile the heat exchange between the integrated columns is maximised.

As Bek-Pederson and Gani (2004) states that driving force is applied in multicomponent systems that has varies physical or chemical properties between different phases will existing together. Therefore, it is advantageous to perform a driving force analysis at the earliest possible stage of the design of a process.

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 multicomponent 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 (vapour-liquid) system (Bek-Pederson and Gani, 2004).

According to Thompson and King (1972) the number of different sequences grows rapidly as the number of products gradually increases. Imagine if the sequence has 11 numbers of products and the number of possible sequences should be 16,796 sequences. The problem happens to the engineer whereby need to analyse each individual sequence in order to have a favourable sequence of the separation process.

The question that needs to be answered here is there any method or approach that will able to improve the existing distillation columns sequence energy saving performance without having any major modification to the major unit operations.

Therefore, the number of suggested alternatives sequences becomes bigger and the analysis becomes more complex, complicated and time consuming. As a result, designing or retrofitting distillation columns sequence with less energy requirement become more difficult. It is highly demanded now to have a simple methodology that will able to design or retrofit the existing direct sequence of distillation columns with minimum energy requirement. In addition, the design and retrofit solution of these energy efficient distillation columns needs also be practiced for the industry purpose which requires less modification efforts.

The objective of this paper is to present the retrofitting analysis for the direct sequence natural gas liquids (NGLs) separation process and to analyse the process sensitivity with respect to feed conditions. To perform the study and analysis, the energy efficient NGLs separation process methodology is developed. Accordingly, the methodology consists of four hierarchical stages. 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. Next, the findings were discussed and summarised.

2. Methodology

This section discusses in general the methodology in finding the best NGLs distillation columns sequence which will use less energy than the direct sequence. Accordingly, the methodology consists of four hierarchical steps as shown in Figure 1.

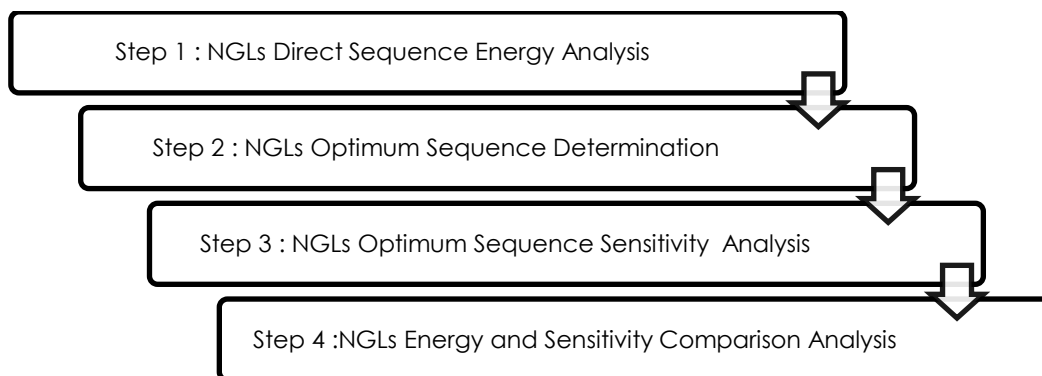


Figure 1: Methodology in finding the best NGLs distillation column sequence

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 NGLs is simulated and the energy used is analysed using a simple and reliable shortcut method distillation column in Aspen HYSYS environment (Aspen Hysis, 2015).

Then in the second step, the optimum sequence was determined by using driving force method to improve energy efficiency distillation column. The optimum sequence was prepared according to the procedure used by Mustafa et al. (2014). 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 to maintain the separation is at the minimum.

In the third step, the optimum sequence was analysed in term of energy and sensitivity analysis using a simple and reliable shortcut method distillation column in Aspen HYSYS environment. In this step, another two sequences which is indirect and direct-indirect sequence was developed. The feed conditions such as pressure, temperature and flowrate will be change to analyse the sensitivity of direct sequence.

Finally, the energy and sensitivity analysis between the direct sequence, optimum sequence, indirect sequence and direct-indirect sequence are compared in the fourth step. A number of studies have found that sequence that is determined by driving force method has used less energy consumption compared to other sequences (Rahimi et al., 2015).

3. Result and Discussion

3.1 Direct Sequence

Table 1 lists the data on the original composition of the natural gas liquids. As illustrated in Figure 2 that is the direct sequence of NGLs, methane will be separated first followed by ethane. The last component that will be separated is *n*-Heptane due to low volatility and high boiling point.

Table 1: Original feed condition of NGLs

Component	Feed conditions	
	Molar flow (kg/h)	Boiling Points (°C)
Methane	991.66	-161.50
Ethane	87,179.69	-88.60
Propane	87,268.17	-42.10
<i>i</i> -Butane	26,803.59	-11.30
<i>n</i> -Butane	57,180.35	-0.50
<i>i</i> -Pentane	20,649.83	-27.88
<i>n</i> -Pentane	14,600.65	36.06
<i>n</i> -Hexane	17,559.16	68.73
<i>n</i> -Heptane	9,099.56	98.43
Temperature	60.17 °C	
Pressure	33.37 bar	

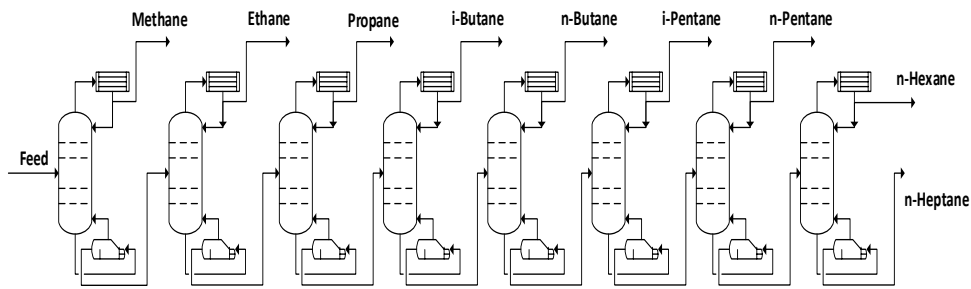


Figure 2: Simplified flow sheet illustrating the direct sequence of NGLs separation process

3.2 Driving Force Sequence

Based on the original condition (Table 1) of the natural gas liquids and their thermophysical properties, driving force curves were plotted prior to determining the optimal sequence. It can be seen from Figure 3 that the curve with the maximum driving force denotes the separation of methane and ethane and the minimum denotes the separation of *n*-Hexane and *n*-Heptane. After that, the optimal sequence was determined and constructed in the simulation environment of Aspen HYSYS as shown in Figure 4. The first column would separate the pair with highest driving force and so on until the pair with the lowest driving force.

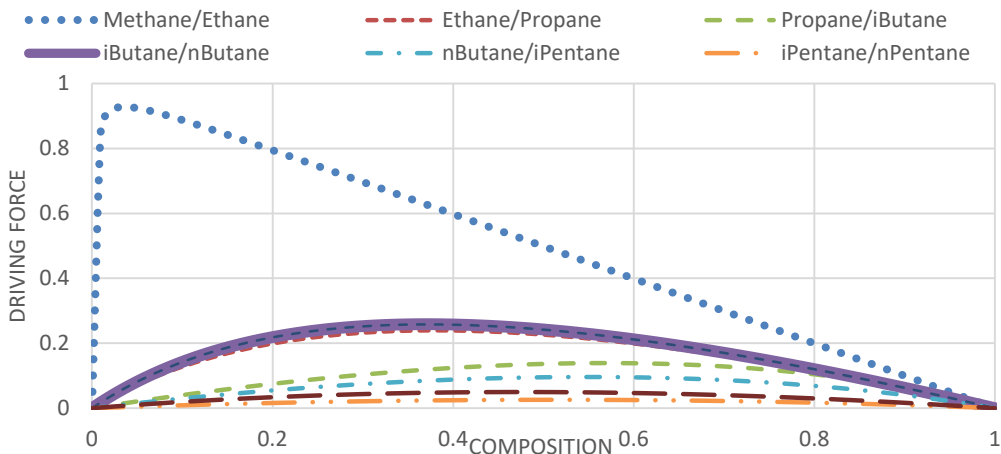


Figure 3: Driving Force curves for set of binary component at uniform pressure

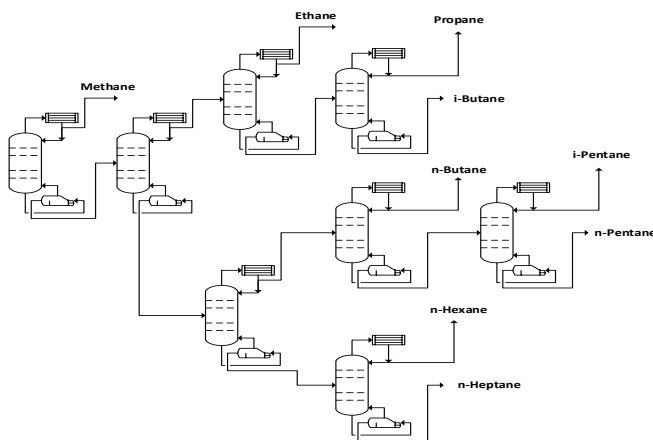


Figure 4: Simplified flow sheet illustrating the driving force sequence of NGLs separation process

3.3 Energy Analysis

The direct sequence, along with three other sequences (optimal, indirect, and direct-indirect), 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. The results of the total energy consumption for each sequence were presented in Table 2.

Table 2: Energy comparison for Natural Gas Liquids separation process

Sequences	Total energy consumed (kW)	Energy saving (%)
Direct	350,065	-
Optimal	338,368	3.3
Indirect	524,099	-49.7
Direct Indirect	378,838	-8.1

Table 2 shows that the optimal sequence determined using driving force concept able to reduce the highest energy around 3.3 % (11.7 MW) compared to other sequences (where other sequences have higher energy requirement). The direct sequence can be defined as the non-integrated configuration with the bottom product of the first column providing the feed to the second column. In the so called indirect sequence the distillate of the first column provides the feed to the second column. The combination of both sequences is called direct indirect sequence.

3.4 Sensitivity Analysis

In order to analyse the sequences' sensitivity, their 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. Thus, 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 the presence of disturbance than other sequences as stated by Hamid et al. (2010).

Table 3: Sensitivity comparison for NGLs separation process with respect to feed conditions

Sensitivity of each sequence	Driving force	Direct-Indirect	Indirect
Original	-	-	-
105 % Flowrate	1.05	1.63	1.18
95 % Flowrate	1.05	1.63	1.18
Temperature +5 °C	-659.49	-659.97	-838.84
Temperature -5 °C	-300.46	-300.46	-112.08

4. Conclusion

The direct sequence of NGLs distillation columns was retrofitted by the driving force sequence. The results show that a maximum energy saving of 11.7 MW was achieved when the optimal (driving force) sequence was compared with the existing direct sequence. For sensitivity analysis, the results show that the driving force had the best sensitivity compared to other sequences. The findings of our research have considerable implication on designing the best sequence that can retrofit the direct sequence in NGLs separation process in an easy, practical and systematic manner.

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