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Energy Efficiency Improvement in the Natural Gas Liquids Fractionation Unit

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The objective of this paper is to present the study and analysis of the energy efficiency for the natural gas liquids (NGLs) fractionation sequence by using driving force method. To perform the studies and analysis, the energy efficient NGLs fractionation plant methodology is developed. Hence, 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 distillation columns sequence of NGLs fractionation unit. By using the driving force method, maximum of 21 % energy reduction is able to be achieved by changing the sequence of NGLs fractionation unit. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for NGLs fractionation. These findings show that the methodology is able to design energy efficient distillation columns for NGLs fractionation sequence in an easy, practical and systematic manner.

1. Introduction

Most natural gas is processed to remove the heavier hydrocarbon liquids from the natural gas stream. These heavier hydrocarbon liquids, commonly referred to as natural gas liquids (NGLs), will be recovered into their component parts, or fractions, using a distillation process known as fractionation. NGLs normally have significantly greater value as separate marketable products that as part of the natural gas stream. Lighter NGL fractions, such as ethane, propane, and butanes, can be sold as fuel or feedstock to refineries and petrochemical plants, while the heavier fractions can be used as gasoline-blending stock. Distillation is the primary separation process widely used in the NGLs processing. Although it has many advantages, the main drawback is its large energy requirement, which can significantly influence the overall plant profitability. This highly energy consuming unit shows opportunities for energy saving (Pejpichestakul and Siemanond, 2013). There is no denying the fact that energy considerations will have a more significant impact on distillation design and retrofitting in the future.

The determination of feasible sequences of multiple distillation columns, whether on the basis of minimum overall energy consumption, total annualized costs, sustainability, or some other metric, has been the subject of academic and industrial investigation for many years. A large number of researches have been conducted to highlight the advantages of a variety of methodologies for determining the best sequence from a given number component feed mixture. Although distillation is an expensive operation in terms of capital and operating costs, it continues to be the most important separation technique, even for non-ideal and azeotropic mixtures (Grossmann et al., 1999). A general review of distillation synthesis has been

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done, for example by using heuristic method (Westerberg,1985), mathematical programming (Floquet et al., 1988), simulated annealing (Floquet et al., 1994) and residue curve maps (Gert-Jan and Liu, 1994). Several approaches have been proposed for the design of efficient separation systems; heuristic methods (Seader and Westerberg, 1977), evolutionary techniques (Stephanopoulos and Westerberg, 1976), superstructure optimization (Floudas, 1995) and graphical methods (Mustafa et al., 2014a) which further in Mustafa et al. (2014b).

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. The McCabe-Thiele has been used as a basic and simple technique to determine the design values of distillation column (Wang and Mansoori, 1994). Driving force method usually uses in the earliest stage of designing distillation column in order to successfully achieve the desired separation. In distillation column, driving force is the difference between composition in vapour phase and liquid phase which occurs when the difference of properties such as boiling point and vapour pressure (Bek-Pedersen and Gani, 2004). 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). The more recent and updated book has been published by Klemeš et al (2014).

Optimization of distillation column operations is essential in order to achieve energy efficiency while meeting product quality constraints (Osuolale and Zhang, 2014). Significant savings in the utilities for NGLs fractionation plant can be achieved by using driving force method in innovative configurations. However, the conventional distillation column may be used in NGLs fractionation design, and only the configurations/sequences need to be changed.

The innovative configurations may be generated by observing thermodynamic inefficiencies in the conventional NGLs fractionation designs. These are typically apparent in relationships between the primary process variables such as temperature, pressure, and compositions. The relationships may be observed through conventional analysis such as McCabe-Thiele diagram, composite heating and cooling curves, and temperature-composition plots. Because the multiple products produced by the NGLs fractionation plant and because of the large amount of energy required, NGLs fractionation plant provides several opportunities for economical process improvement through improved thermodynamic efficiency. This can be systematically and effectively achieved by using driving force method.

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

In this paper, the study and analysis of the energy saving improvement for the NGLs fractionation plant sequence by using driving force method without having any major modifications to the major separation units, is presented. There will be only modifications to the separation sequences based on the driving force results, which will reduce the energy requirement. To perform the study and analysis, the energy efficient NGLs fractionation plant sequence methodology is developed. Accordingly, the methodology consists of four hierarchical steps. In the first step, a simple and reliable short-cut method is used to simulate a base (existing) NGLs sequence. The energy used in the base sequence is taken as a reference. In the second stage, an optimal NGLs 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 in step three, where the energy used in the optimal sequence is analysed. Finally, the energy used in the optimal sequence is compared with the base sequence.

2. Methodology for Energy Efficient Distillation Column Sequence

The energy efficient distillation columns (EEDCs) sequence methodology is developed based on the driving force method which can save energy as well as economical distillation column sequence. Hence, the methodology consists of four hierarchical steps as shown in Figure 1.

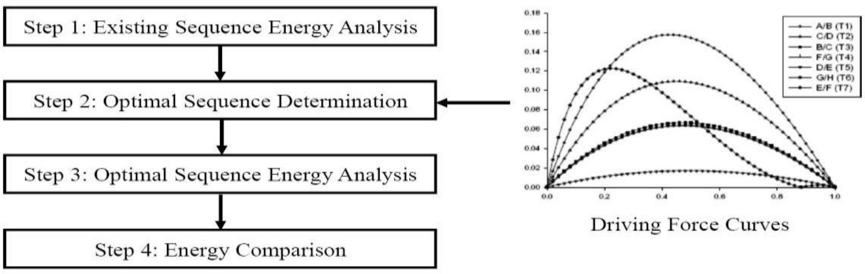

Figure 1: Energy efficient distillation columns sequence methodology (Mustafa et al., 2014a,b)

The first step deals with the existing sequence energy analysis, which will become the base sequence used for verification purposes. In this step, the existing sequence for NGLs is simulated and the energy used is analyzed by using simple and reliable shortcut method distillation column in Aspen HYSYS environment. Then in the second step, the optimum sequence was determined by using driving force method to improve energy efficiency in distillation column. In the third step, the optimum sequence was analyzed in term of energy analysis by using a simple and reliable shortcut method distillation column in Aspen HYSYS environment. Finally, the energy analysis between the existing sequence and the optimum sequence by using driving force method are compared in the fourth step. The economic performance for the optimum sequence is also evaluated in this step.
The capability of this methodology is tested in designing minimum energy distillation column sequence for NGLs fractionation process, which consists of nine compounds (methane, ethane, propane, *i*-butane, *n*-butane, *i*-pentane, *n*-pentane, *n*-hexane, *n*-heptane) with eight direct sequence distillation columns.

3. Case Study: Natural Gas Liquids (NGLs) Fractionation Plant

The capability of proposed methodology is tested in designing minimum energy distillation column sequence for NGLs fractionation process. The objective of the NGLs fractionation process is to recover individual fractions of NGLs by using distillation columns. NGLs normally have significantly greater value as separate marketable products that as part of the natural gas stream. Lighter NGL fractions, such as ethane, propane, and butanes, can be sold as fuel or feedstock to refineries and petrochemical plants, while the heavier fractions can be used as gasoline-blending stock. The NGLs fractionation process consists of nine compounds (methane, ethane, propane, *i*-butane, *n*-butane, *i*-pentane, *n*-pentane, *n*-hexane, *n*-heptane) with eight direct sequence distillation columns

3.1 Existing Sequence Energy Analysis

Figure 2 illustrates the existing sequence separation of the NGLs fractionation process. The feed composition, temperature, and pressure are described in Table 1. The existing NGLs fractionation process was simulated using a simple and reliable short-cut method within Aspen HYSYS software. The total energy required to achieve 99.9 % of product recovery are 155.95 MW.

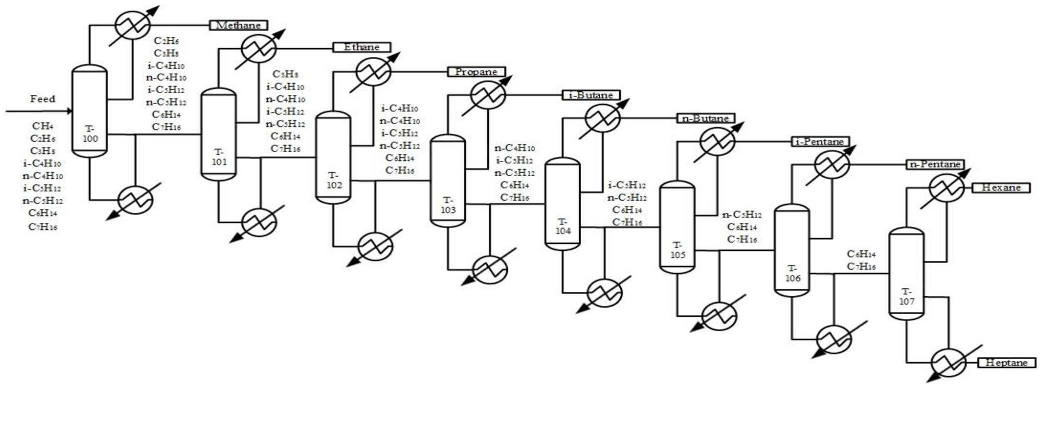

Figure 2: Flowsheet illustrating the existing direct sequence of NGLs fractionation process

Table1: Feed conditions of the mixture

	Feed conditions	
Components	Mass Flow (kg/h)	Molar Flow (kg/h)
Methane	47,744	2,976
Ethane	8,059	268
Propane	10,385	235.5
i-Butane	5,900	101.5
n-Butane	6,946	119.5
i-Pentane	6,494	90
n-Pentane	5,808	80.5
n-Hexane	11,203	130
n-Heptane	100,105	999
Temperature (°C)	55.83	
Pressure (bar)	31.37	

3.2 Optimal Sequence Determination

The optimal NGLs sequence was determined by using driving force method. All individual driving force for all binary pair (Methane/ethane, ethane/propane, propane/i-butane,i-butane/n-butane, n-butane/i-pentane, i-pentane/ n-pentane, n-pentane/ hexane, hexane/ hexane) was plotted as shown in the Figure 3, and the optimal sequence was determined based on the plotting driving force curves. The new sequence based on driving force is shown in the Figure 4.

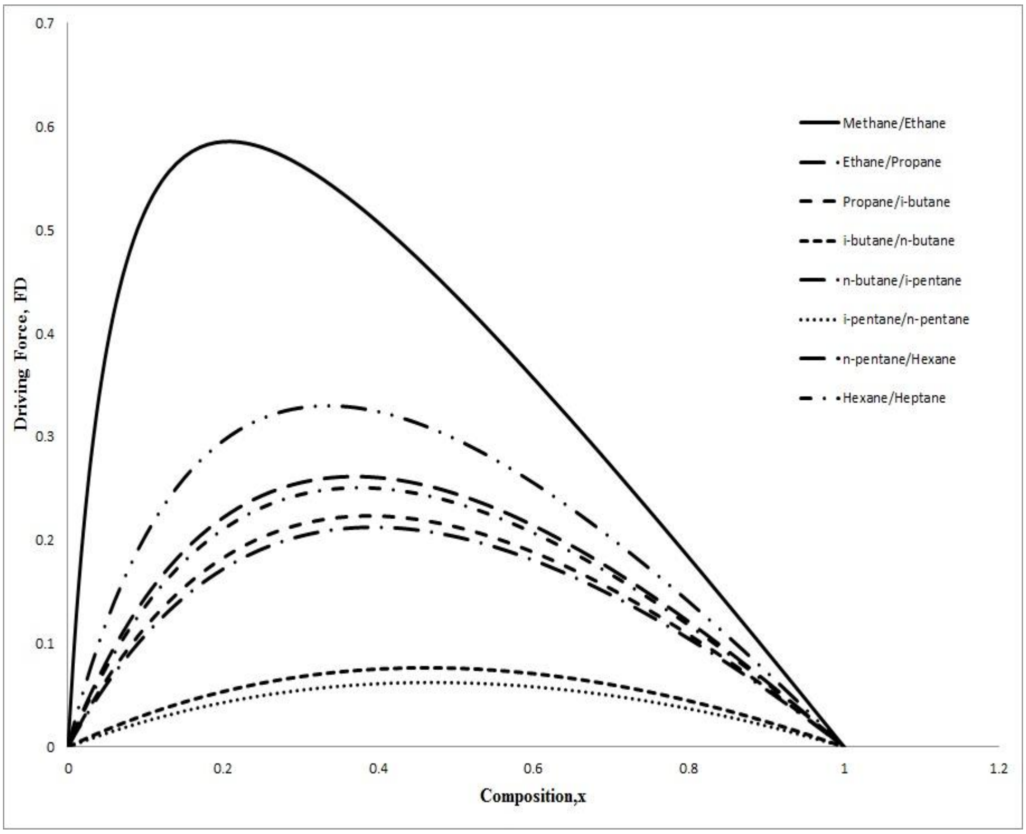

Figure 3: Driving force curves for a set of binary components at uniform pressure

3.3 Optimal Sequence Energy Analysis

The new optimal sequence was simulated using short-cut method within Aspen HYSYS environment where a total of 122.90 MW of energy was used for the same product recovery.

3.4 Energy Comparison

Total energy used to recover every single component in NGLs 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 21.6 % energy reduction was able to achieve by changing the sequence suggested by the driving force method.

Table 2: Energy comparison between direct sequence and driving force sequence for NGLs fractionation process

Distillation Column Unit	Direct Sequence (MW)	Driving Force Sequence	Percentage Difference (%)
Total Condenser Duty (MW)	75.10	58.58	22.01
Total Reboiler Duty (MW)	80.85	64.32	20.44
Total Energy (MW)	155.95	122.9	21.19

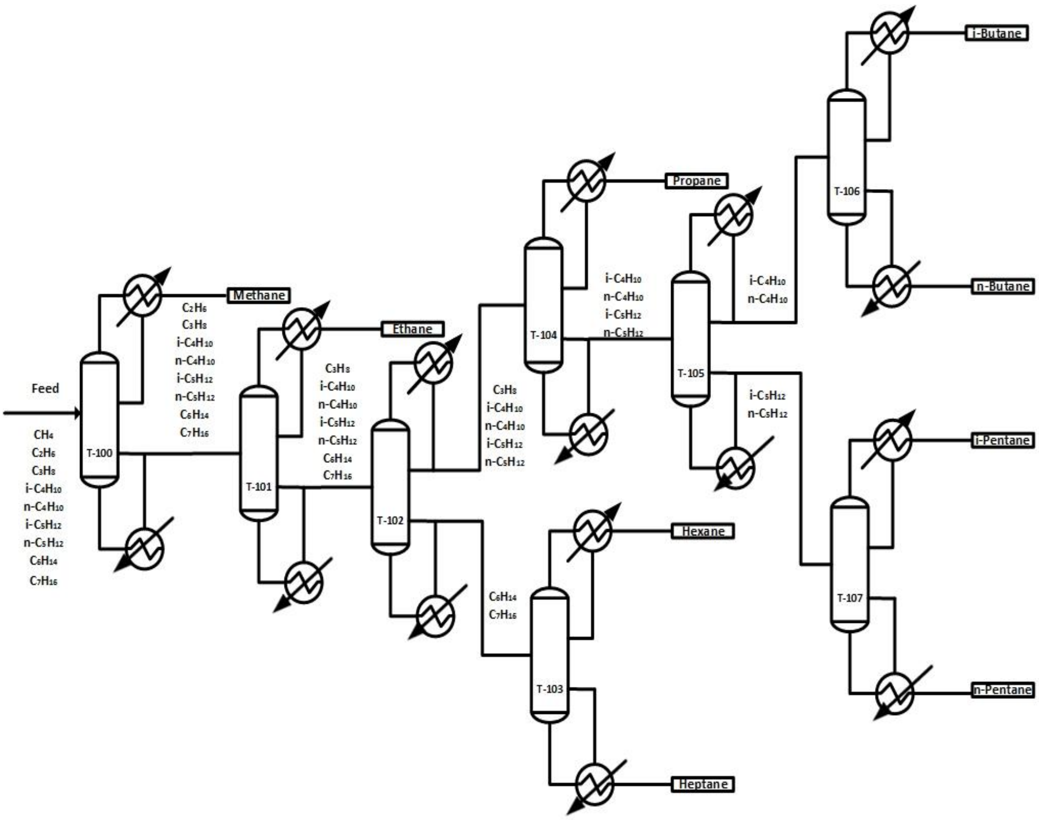

Figure 4: Flowsheet illustrating the optimal driving force sequence of NGLs fractionation process

4. Conclusion

The study and analysis of the energy saving improvement for the NGLs fractionation plant by using driving force method has been successfully performed. The existing NGLs fractionation process consists of nine compounds (methane, ethane, propane, i-butane, n-butane, i-pentane, n-pentane, n-hexane, n-heptane) with eight direct sequence distillation columns was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 155.95 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 122.9 MW of energy was used of the same product recovery. The results show that the maximum of 21.19 % 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. All of this findings show that the methodology is able to design minimum energy distillation column sequence for NGLs fractionation process in an easy, practical and systematic manner.

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