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Optimal Synthesis of Energy Efficient Distillation Columns Sequence of Natural Gas Liquids

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Abstract. The objective of this paper is to present the study and analysis of the energy saving improvement for the NGLs fractionation plant sequence by using driving force method. To perform the study and analysis, the energy efficient NGLs fractionation plant sequence methodology is developed. Accordingly, 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 minimum energy distillation column sequence for NGLs fractionation process. The results show that the maximum of 46% 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.

Keywords:distillation column sequence; driving force; energy efficient; natural gas liquids.

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 Natural Gas Liquids (NGLs) processing. Although it has many advantages, the main drawback is its large energy requirement, which can significantly influence the overall plant profitability. 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

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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 [1]. 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 [1].

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 analyzed. Finally, the energy used in the optimal sequence is compared with the base sequence.

2 Energy Efficient Distillation Columns Sequence Methodology

To perform the study and analysis of the energy saving improvement for the energy efficient NGLs fractionation plant sequence, energy efficient distillation columns (EEDCs) sequence methodology is developed based on the driving force method. Accordingly, the methodology consists of four hierarchical steps as shown in Figure 1.

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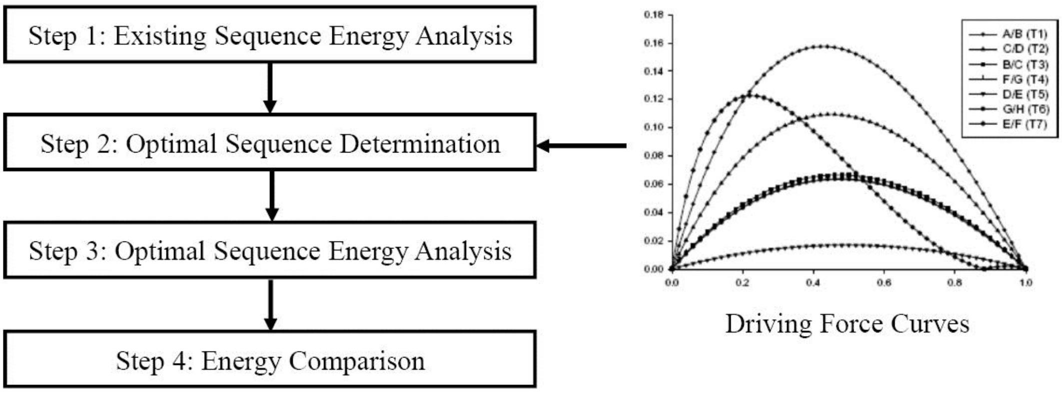

Figure 1 Energy efficient distillation columns sequence methodology [2].

In the first step, a simple and reliable short-cut method of process simulator (Aspen HYSYS) is used to simulate a base (existing) NGLs 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 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. According to Bek-Pederson and Gani, the optimal sequence with the most energy efficient can be determined from the plotted driving force curves [1]. 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.

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.

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3 Case Studies: 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 a 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 indirect sequence distillation columns for case study 1 (CS1), with eight indirect-direct sequence distillation columns for case study 2 (CS2) and with eight indirect-slitter sequence distillation columns for case study 3 (CS3).

3.1. Case Study 1: Indirect Sequence

Step 1: Existing Sequence Energy Analysis

Figure 2 illustrates the existing separation sequence of the NGLs fractionation process.The feed composition, temperature and pressure are described in Table 1. The existing NGLs fractionationprocess was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 484.7 MW energy used to achieve 99.9% of product recovery.

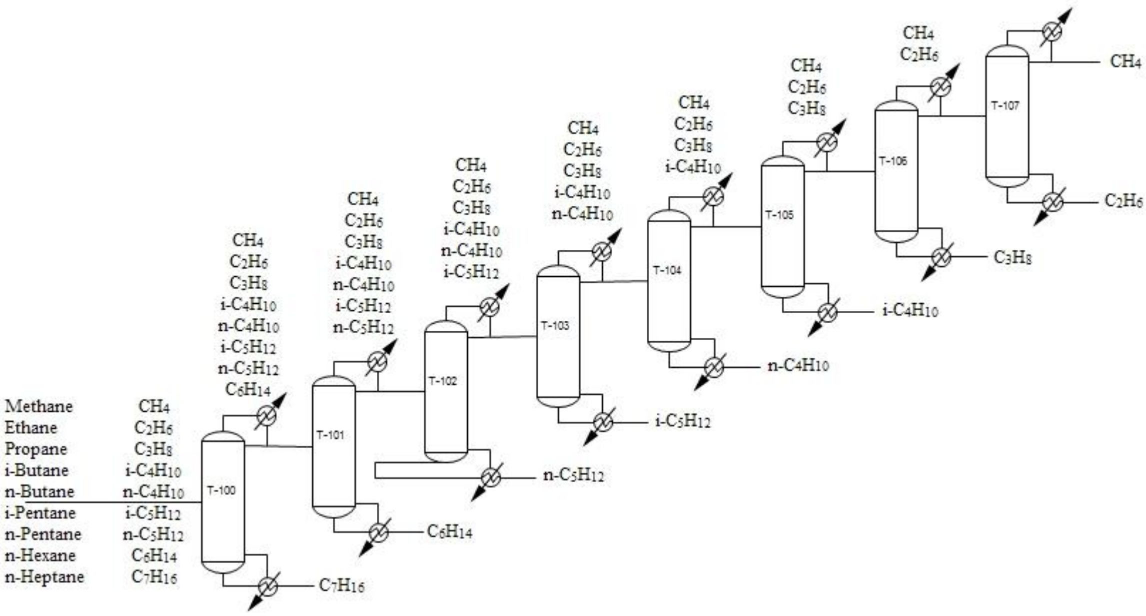

Figure 2. Simplified flow sheet illustrating the existing indirect sequence of NGLs fractionation process for case study 1.

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Table 1. Feed conditions of the mixture [3].

	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 (ºC)	55.83	
Pressure (bar)	31.37	

Step 2: Optimal Sequence Determination

The optimal NGLs 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.

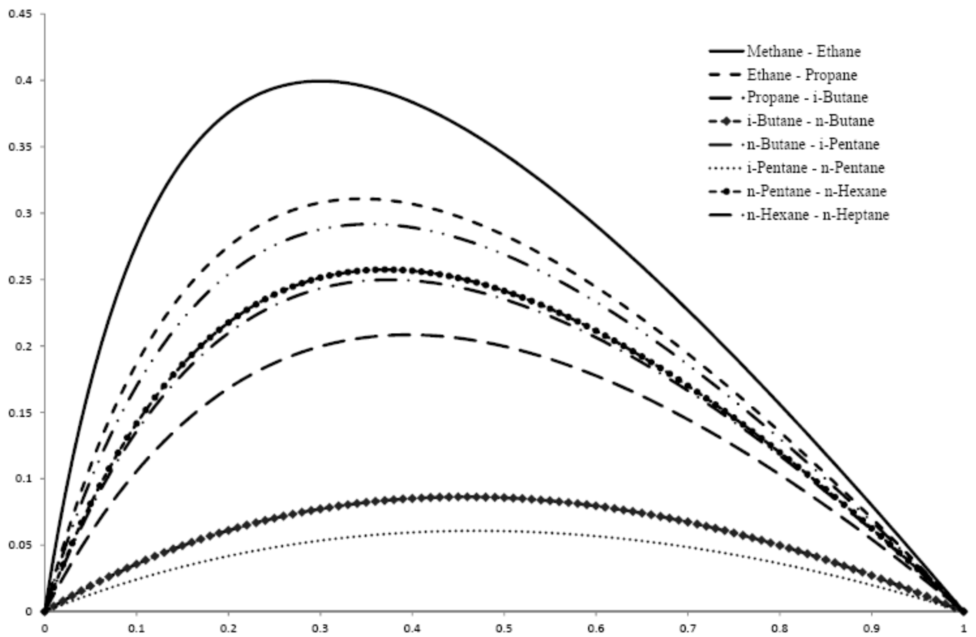

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Figure 3. Driving Force curves for set of binary component at uniform pressure.

Step 3: Optimal Sequence Energy Analysis

A new optimal sequence determined by driving force method (see Figure 4) was simulated using a short-cut method within Aspen HYSYS environment where a total of 262.3 MW of energy was used for the same product recovery.

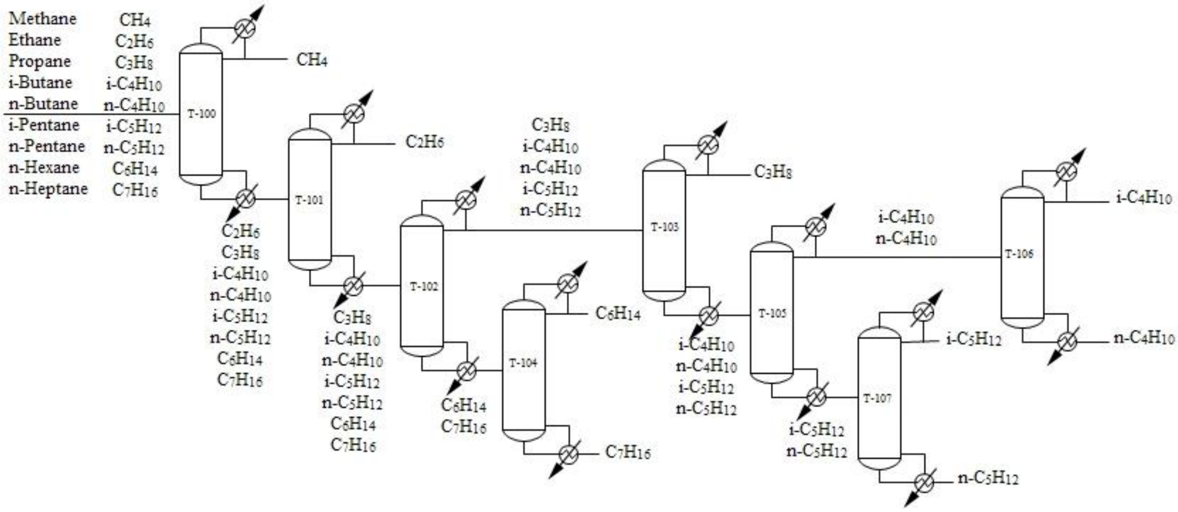

Figure 4. Simplified flow sheet illustrating the optimal Driving Force sequence of NGLs fractionation process.

Step 4: Energy Comparison

Total energy used to recover every single NGLs fractions for the existing indirect sequence and the new optimal sequence determined by the driving force method is shown in Table 2. The results show that 46% energy reduction was able to achieve by changing the sequence suggested by the driving force method.

Table 2. Energy comparison for indirect sequence and driving force sequence for MGLs fractionation process.

	Indirect Sequence	Driving Force Sequence	Percentage (%)
Total Energy Condenser (MW)	255.8	144.6	**43.5**
Total Energy Reboiler (MW)	228.9	117.7	**48.6**
Total Energy (MW)	**484.7**	**262.3**	**45.9**

3.2. Case Study 2: Indirect-Direct Sequence

Step 1: Existing Sequence Energy Analysis

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Figure5 illustrates the existing indirect-direct separation sequence of the NGLs fractionation process.The feed composition, temperature and pressure are the same as described in Table 1. The existing NGLs fractionationprocess was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 456.0 MW energy used to achieve 99.9% of product recovery

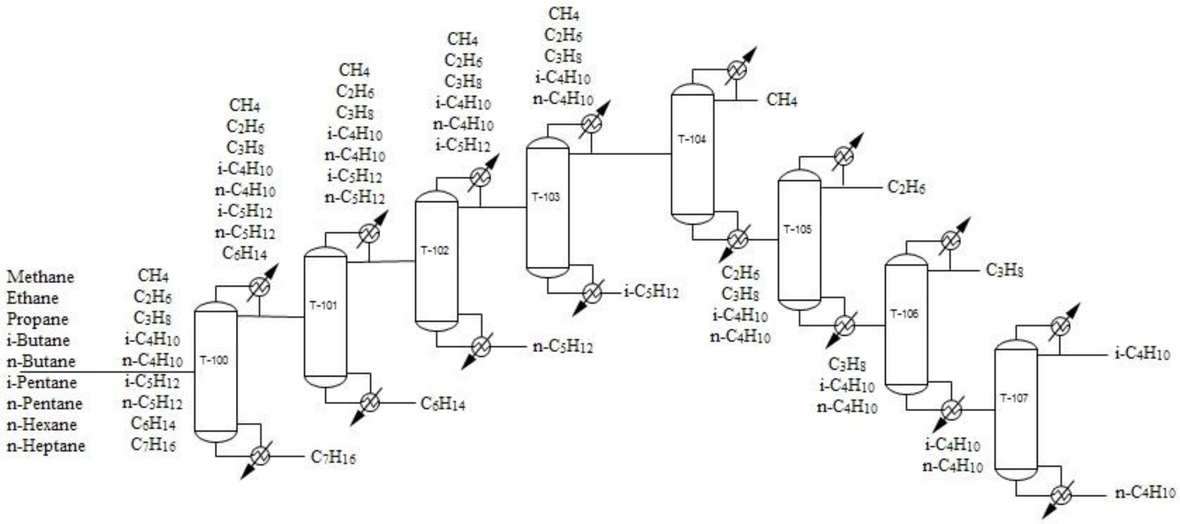

Figure 5. Simplified flow sheet illustrating the existing indirect-direct sequence of NGLs fractionation process for case study 2.

Step 2: Optimal Sequence Determination

The optimal NGLs sequence was determined by using driving force methodas shown in the Figure 3. The optimal sequence based on driving force is shown in the Figure 4.

Step 3: Optimal Sequence Energy Analysis

The optimal sequence determined by driving force method (see Figure 4) was simulated using a short-cut method within Aspen HYSYS environment where a total of 262.3 MW of energy was used for the same product recovery.

Step 4: Energy Comparison

Total energy used to recover every single NGLs fractions for the existing indirect-direct sequence and the new optimal sequence determined by the driving force method is shown in Table 3. The results show that 43% energy reduction was able to achieve by changing the sequence suggested by the driving force method.

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Table 3. Energy comparison for indirect-direct sequence and driving force sequence for NGLs fractionation process.

	Indirect-Direct Sequence	Driving Force Sequence	Percentage (%)
Total Energy Condenser (MW)	241.5	144.6	**40.1**
Total Energy Reboiler (MW)	214.5	117.7	**45.1**
Total Energy (MW)	**456.0**	**262.3**	**42.5**

3.3. Case Study 3: Indirect-Splitter Sequence

Step 1: Existing Sequence Energy Analysis

Figure6 illustrates the existing indirect-splitterseparation sequence of the NGLs fractionation process.The feed composition, temperature and pressure are the same as described in Table 1. The existing NGLs fractionationprocess was simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 338.2 MW energy used to achieve 99.9% of product recovery.

Step 2: Optimal Sequence Determination

The optimal NGLs 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.

Step 3: Optimal Sequence Energy Analysis

A new optimal sequence determined by driving force method (see Figure 4) was simulated using a short-cut method within Aspen HYSYS environment where a total of 262.3 MW of energy was used for the same product recovery.

Step 4: Energy Comparison

Total energy used to recover every single NGLs fractions for the existing direct sequence and the new optimal sequence determined by the driving force method is shown in Table 4. The results show that22% 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.

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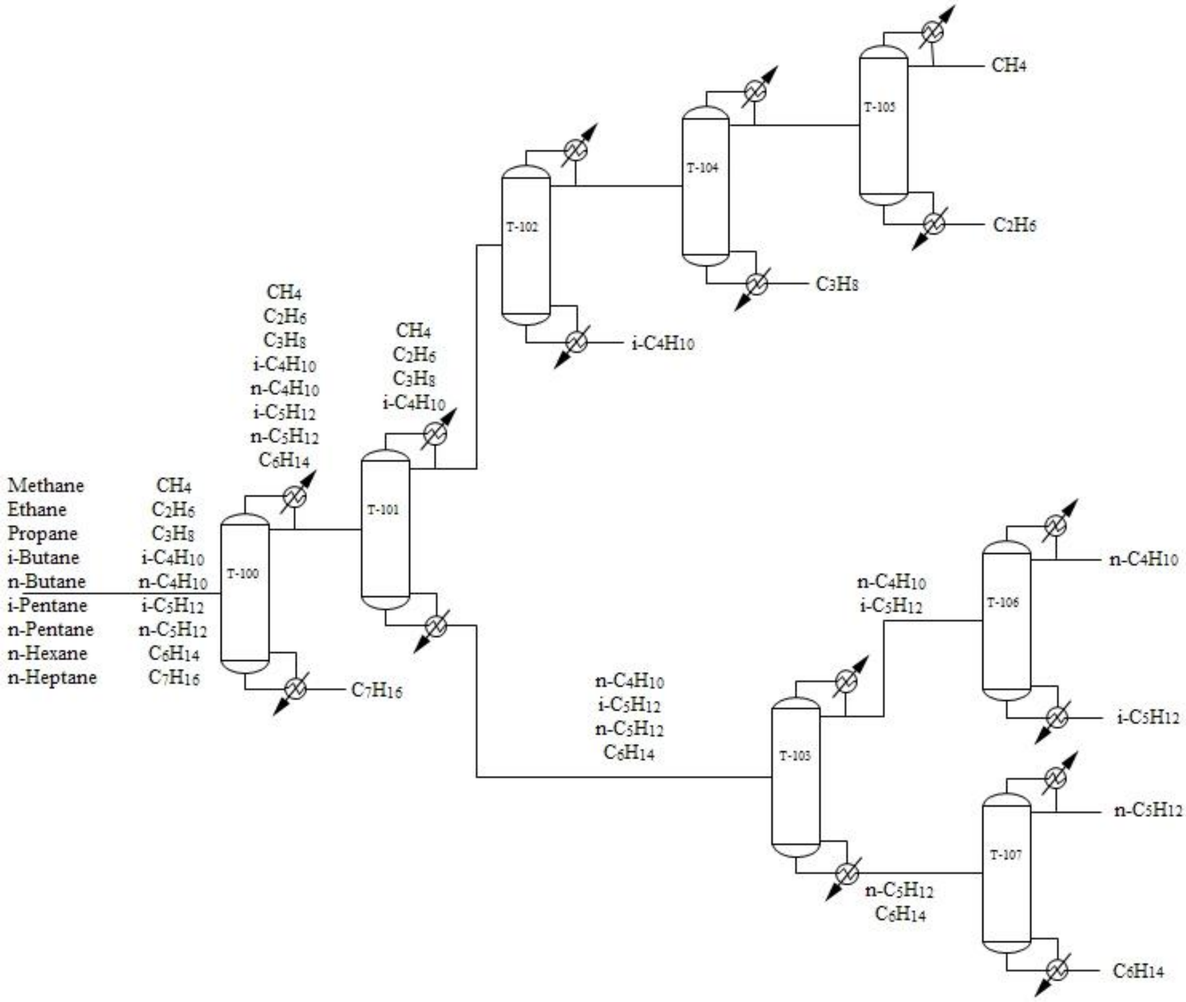

Figure 6. Simplified flow sheet illustrating the existing indirect-splitter sequence of NGLs fractionation process for case study 3.

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Table 4. Energy comparison for indirect-splitter sequence and driving force sequence for NGLs fractionation process.

	Indirect-Splitter Sequence	Driving Force Sequence	Percentage (%)
Total Energy Condenser (MW)	182.5	144.6	**20.8**
Total Energy Reboiler (MW)	155.7	117.7	**24.4**
Total Energy (MW)	**338.2**	**262.3**	**22.4**

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 indirect sequence (case study 1), indirect-direct sequence (case study 2) and indirect-splitter (case study 3) distillation columns were simulated using a simple and reliable short-cut method within Aspen HYSYS environment. A total of 484.7 MW (for case study 1), 456.0 MW (for case study 2) and 338.2 MW (for case study 3) 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 262.3 MW of energy was used of the same product recovery. The results show that 46% (for case study 1), 43% (for case study 2) and 23% (for case study 3) energy reduction were 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 up to 46%. 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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