Energy Efficient Distillation Columns Design For Retrofit NGLs Fractionation Process

Mohd Faris Mustafa[1,a], Noor Asma Fazli Abdul Samad[3,b], Kamarul Asri Ibrahim[1,c],Norazana Ibrahim[2,d], Mohd Kamaruddin Abd. Hamid[1,e*]

[1]Process Systems Engineering Centre, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

[2]UTM-MPRC Institute of Oil & Gas, Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

[3]Faculty of Chemical Engineering and Natural Resources, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia

[a]aish.freze@gmail.com,[b]asmafazli@ump.edu.my,[c]kamarul@cheme.utm.my, [d]norazana@petroleum.utm.my,[e]kamaruddin@cheme.utm.my*

Keywords: Energy efficient distillation columns, driving force, pinch technology

Abstract. Distillation is the primary separation process widely used in the industrial chemical process. Although it has many advantages, the main drawback is its large energy requirement, which may significantly influence the overall plant profitability. However, the large energy requirement of these processes can be systematically reduced by using driving force and energy integration methods. This paper presents a methodology for designing energy efficient distillation columns systems based on those two methods. Generally, the proposed methodology consists of four hierarchical steps. In the first step, the system of distillation columns for multicomponent separation is designed based on the conventional distillation column design (shortcut) method. Then, the conventional distillation columns systems design is improved in terms of energy saving by using driving force method in the second step. It is expected in the third step that the distillation columns systems design can be further improved in terms of energy saving by using energy integration method. Finally, the distillation columns systems design is evaluated in terms of economic performance. The simulation results by using Aspen HYSYS have shown that the driving force sequence by using shortcut method for NGLs has energy savings with 55% reduction compared to a direct method with shortcut method. It can be verified that the proposed methodology has the capability in designing energy efficient distillation columns in an easy, systematic and practical manners.

Introduction

The demand for energy has been continuously increasing for years and operation units with large energy demand such as distillation columns have become more difficult to be supplied. The energy efficiency of distillation columns systems becomes an important criterion during retrofitting and design of industrial chemical processes. On the other hand, reducing energy requirements of distillation column systems leads to lower CO_2 emission. This becomes the reason why the plant designers need to take the different energy saving solutions into consideration and subsequently choose the best distillation columns systems design for the specific separation task.

Reducing product cost in chemical industry has been very effectively applied in energy saving method for distillation columns by using heat integration columns system. Heat integration by two columns is based on an idea to match utilizing overhead vapour of one column in order to provide heat content for boiling up a second column. Heat integration column is the process where the heat of hot streams is exchanged with the cold streams. In this process the rectifying and stripping sections are designed by internally coupled through the heat exchanger. These designs have proven an enormous improvement by reducing the reboiler and condenser duties which lead to the energy saving efficiency. Therefore, the development of process and energy integration techniques have been developed such as the fully thermally coupled distillation columns (FTCDC or Petlyuk column) and dividing wall columns (DWCs) to reduce energy consumption. The DWCs allows reversible splits with no part of the separation being used twice and it is the main source of its superior energy efficiency over other column configurations. However, Petlyuk systems have strong interactions between their columns because of the thermal integration, which can inhibit their design and operation.

Therefore, a new methodology enabling the design energy efficient distillation columns (EEDCs) is proposed in this paper. Generally, the proposed methodology consists of four hierarchical steps. In the first step, the system of distillation column for multicomponent separation is designed based on the conventional distillation column design method. Then, the conventional distillation columns systems design is improved in terms of energy saving by using driving force method in the second step. It is expected in the third step that the distillation columns systems design can be further improved in terms of energy saving by using energy integration method. Finally, the distillation column systems design is evaluated in in terms of economic performance. By applying the proposed methodology, it is possible to make an early assumption on sequence of distillation column systems that is the best in terms of energy saving. Significant energy savings can be made through the use of distillation column employing the driving force [1] and energy integration [2] methods.

Bek-Pederson and Gani [1] developed a systematic design and synthesis of distillation systems using a driving force based method. This method suggested that at the highest driving force, the separation becomes easiest due to the large difference in composition between the phases and therefore, the energy necessary to achieve the separation task at each individual distillation column is at a minimum. In addition, Sobocan et al. [3] developed a systematic synthesis of energy integrated distillation column systems. This method helps in reducing external energy input of the distillation column systems by minimizing the utility consumption and maximizing the heat exchange between the integrated columns.

This paper presents a methodology for designing energy efficient distillation column systems based on driving force and energy integration methods. In the next section, a review on the energy integrated distillation columns design is discussed followed by a detail of the proposed methodology which consists of four hierarchical steps. The application of this methodology is highlighted through oxygenates case study where the energy efficient distillation columns is systematically designed in term of energy efficient.

Overview of Energy Integrated Distillation Columns Design

The design method for energy integrated distillation columns can be summarized into four types which are: 1) conventional type distillation column with multicomponent separation, 2) conventional type distillation column with driving force, 3) conventional type distillation column with pinch technology and 4) conventional type distillation column with driving force combining with pinch technology. The McCabe-Thiele graphical technique has been used as a basic and simple technique to determine the design values of distillation column [4].

In this study, two graphical methods are used to determine the optimal design for energy efficient, which are driving force and pinch technology. 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 based on the difference of properties such as boiling point and vapour pressure [5]. The ideal designs for distillation column is based on the driving force approach to maximum, which lead to the energy necessary in maintaining the two phase system in minimum or highly energy efficient design. Therefore, in the second type of distillation column design, the driving force method will be used as an additional step in similar conventional distillation column with the present of driving force diagram.

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 [6]. Pinch technology method helps to optimize the heat transfer equipment during temperature crossover between hot streams and cold streams according to the first and second law of thermodynamics. Then, the third type of distillation design method is achieved by using pinch technology in the conventional type of distillation column in order to reduce energy consumption in the process which mean more energy saving can be obtained. Lastly, the design of energy efficient distillation column can be created by combining driving force method with pinch technology in the conventional type of distillation column. Theoretically, by combining these two methods for the conventional type of distillation columns, more energy efficient can be produced.

Methodology for Designing Energy Efficient Distillation Columns Systems

In this section, the development of a systematic methodology for designing energy efficient distillation columns systems based on driving force and energy integration methods is explained in detailed. Basically, the proposed methodology consists of four hierarchical steps as shown in Fig. °1

The first step deals with the conventional distillation columns systems design, which will become the base design used for verification purposes. In this step, the system of distillation column for multicomponent separation is designed based on the conventional distillation column design method. Then, the conventional distillation columns systems design is improved in terms of energy saving by using driving force method in the second step. It is expected in the third step that the distillation columns systems design can be further improved in terms of energy saving by using energy integration method.

Finally, the distillation column systems design is evaluated in in terms of economic performance. By applying the proposed methodology, it is possible to make an early assumption on the type of distillation column systems design that is the best in terms of energy saving and cost.

The simulation models of the studied distillation columns systems are implemented in the Aspen HYSYS process simulator. In the first step, the number of the theoretical trays, location of the feed trays and the reflux ratio are estimated with shortcut design procedure. The results of the shortcut design are then implemented in rigorous column model. In the second step, by fixing the number of the theoretical trays obtained in the previous step, the location of the feed trays and the reflux ratio are estimated by using driving force method. Then, the results of the driving force design are implemented in rigorous column model, and the total energy consumption is compared with the previous shortcut design. In the third step, the energy saving of the distillation columns systems designed by driving force method is further improved by implementing energy integration. The design of the heat exchanger network is synthesized by using thermal pinch method. The results of the heat exchanger network design are then implemented in rigorous column model, and the total energy consumption is compared with the two previous designs. Finally, the economic performance is calculated and analyzed.

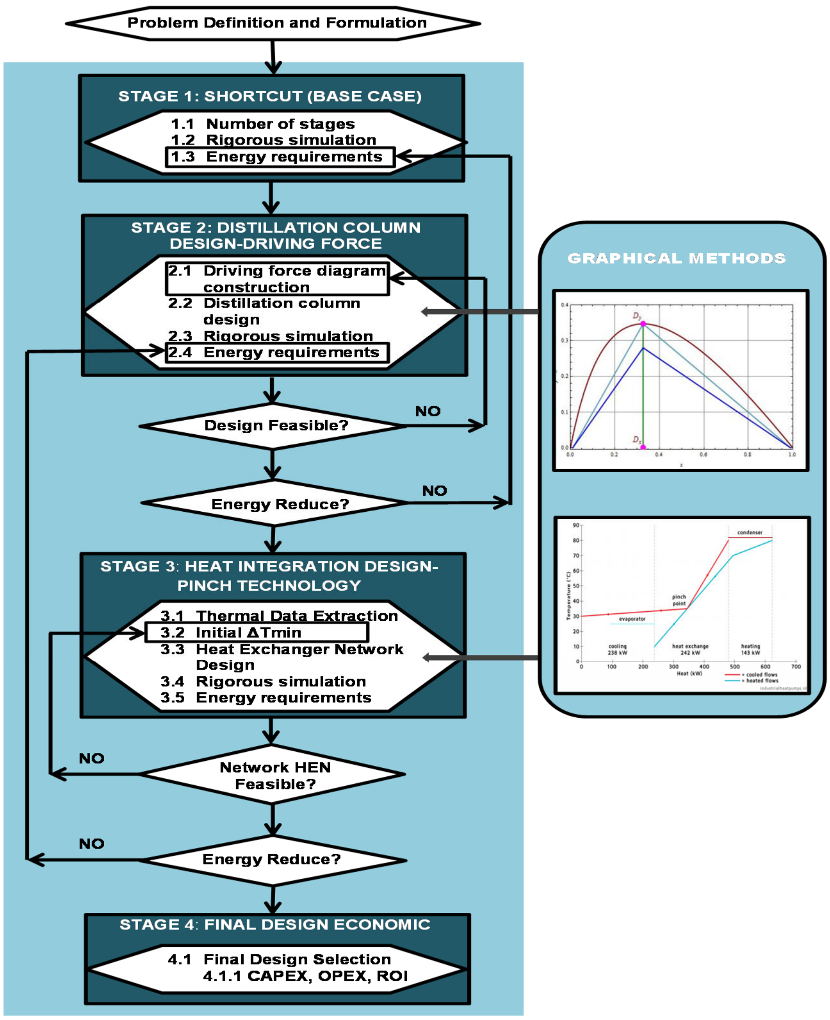

Figure 1. The Methodology for Energy Efficient Distillation Columns

Case Study for Natural Gas Liquid (NGLs) Recovery Process

The separation case study of a NGLs recovery is selected to highlight the application of the proposed methodology as shown in Table 1. The flow rate feed of 321332.66 kg/hr and product mole fraction are presented in Table 1.The temperature of the feed was set at 55.83°C and 31.37 bar pressure. The Aspen HYSYS simulation was used in the case study by applying Peng-Robinson equation of state as the prediction of vapor–liquid equilibrium (VLE).

Table 1. Case study of flow rate feed and product specification

Component	**Mass Flow (kg/hr)**	**Mole Fraction (%)**
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
Total	**321332.66**	**99.99**

Fig 2 shows the driving force diagrams for multicomponent separations of NGLs product. From Fig.2, it can be seen that the plot of separation Methane-Ethane shows the higher point compared to other separations. According to the driving force method, at the higher point at the driving force diagram separation becomes easier and the energy required maintaining that separation is at the minimum. Therefore, by just analysing the driving force diagram, we can identify the best distillation columns sequence that will require less energy. The optimal sequence of the NGLs using driving force method is shown in Fig. 3.

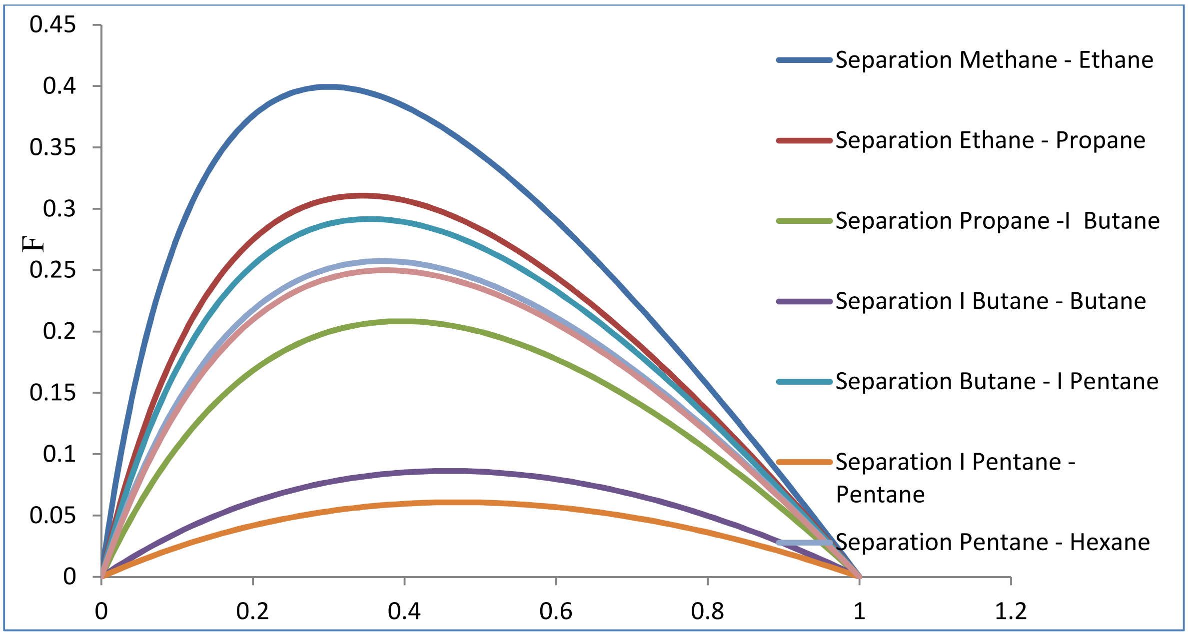

Figure 2. . NGLs driving force diagram for determining the optimal sequence

The sequence obtained from the driving force method is then verified in terms of energy saving by using Aspen HYSYS process simulator (see Fig. 3). Table 2 shows the results for the percentage of energy savings for direct sequences and with driving force sequences by using Aspen HYSYS simulations. In the direct sequence, a total energy of 27.16 MW is obtained using shortcut method compared to a total energy of 12.12 MW obtained from the driving force sequence. This indicates that energy saving with 55% reduction is achieved by employing the driving force sequence in the shortcut method. Therefore, based on this analysis, it is clearly shown the driving force sequence are more favourable compared to the direct sequence as verified by the energy saving.

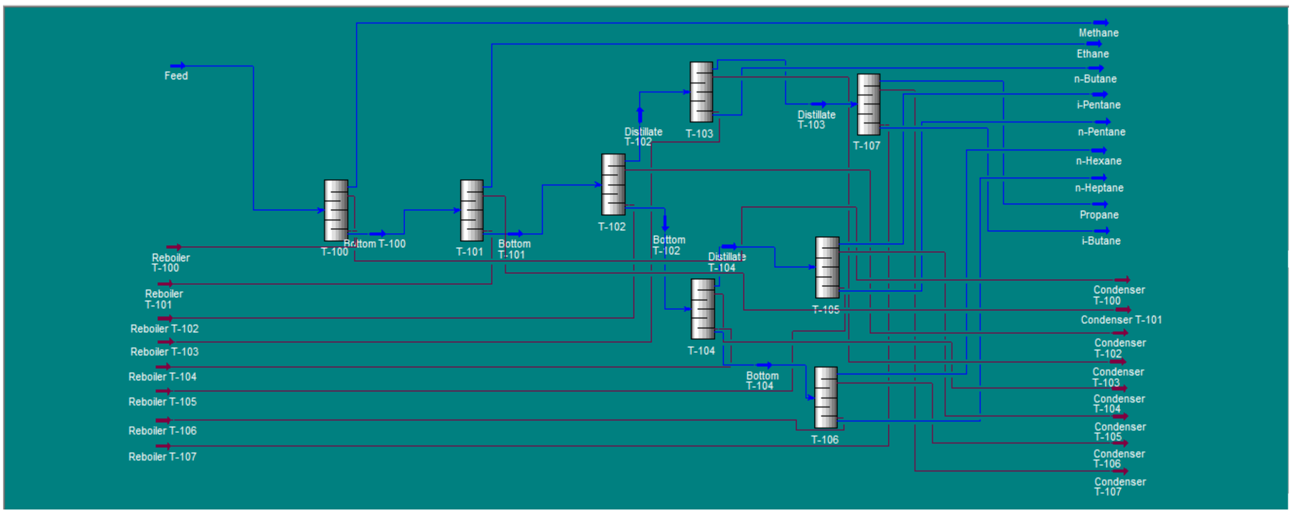

Figure 3. Optimal sequence for NGLs fractionation process

Summary

The methodology for designing energy efficient distillation column systems based on the driving force and heat integration methods has been presented. The methodology has been highlighted using NGLs process case study involving multicomponent mixture. Based on the driving force analysis, it has been shown that driving force sequence by using shortcut method is the best distillation column sequence compared to shortcut method (direct sequence) in term of energy efficient. This is further validated using Aspen HYSIS simulation where an energy saving of 55% is obtained using driving force method in the driving force sequence. Therefore, the feasible energy saving sequence of distillation column systems can be determined systematically using the proposed methodology.

Table 2. Separation of NGLs

Design	Shortcut Method (Direct Sequence)	Shortcut Method (Driving Force Sequence)
Total Energy Condenser, MW	13.53	6.13
Total Energy Reboiler, MW	13.63	5.99
Total Energy, MW	27.16	12.12
Percentage Energy Saving (Direct Sequence), %	**-**	**55**

Acknowledgement

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

References

[1] Bek-Pedersen, E., Gani, R. (2004). Design and Synthesis of Distillation Systems Using a Driving-Force Based Approach. Chemical Engineering and Processing, 43, 251-262.

[2] Kemp, I. C. (2007). Pinch Analysis and Process Integration. A User Guide on Process Integration for the Efficient Use of Energy. Elsevier, Amsterdam, the Netherlands.

[3] Sobocan, G., Glavic, P. (2012). A simple method for systematic synthesis of thermally integrated distillation sequences. Chemical Engineering Journal, 89 (1-3), 155-172.

[4] Wang, J. L., and Mansoori, G. A. (1994). A Revision of the Distillation Theory (Part I). Scientia Ir., 1(3), 267-287.

[5] Bek-Pedersen, E., and Gani, R. (2004). Design and Synthesis of Distillation Systems Using a Driving-Force Based Approach. Chemical Engineering and Processing, 43, 251-262.

[6] Kemp, I. C. (2007). Pinch Analysis and Process Integration. A User Guide on Process Integration for the Efficient Use of Energy. Elsevier, Amsterdam, the Netherlands.