Thermal Energy Approach of a Conventional Propylene/propane Splitter

II. Accuracy method for estimating thermal energy

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This part of the paper proposes a simple and accurate method for estimating specific energy consumption (SEC) and specific low pressure steam consumption (SLPLC). It is expected that the proposed method should help the process engineers in their real-time decisions of the propylene/propane separation by conventional distillation.

Keywords: propylene, propane, splitter, energy, reboiler

Ethylene and propylene, obtained from the pyrolysis of gaseous or liquid raw materials, are two of the most important products in the petrochemical industries. Apart of the steam cracking units, another various petrochemical streams contain olefin and other saturated hydrocarbons. An important step in the manufacture of olefins is separation of the olefin from its mixture with the corresponding paraffin.

Over the time, different processes have been used for the separation of olefin–paraffin mixtures, such as low-temperature distillation, physical or chemical absorption, physical or chemical adsorption and extractive distillation [1-4]. Currently, the separation of propylene-propane mixture is carried out by conventional distillation, which is a highly energy-intensive process due to the low relative volatilities of components.

The steady – state simulation of conventional propylene-propane separation was performed in the first part of this study. In the second part of our work, it is proposed a simple and rapid method which allows the graphical correlations between the thermal energy requirement or the low steam consumption and reflux flowrate of the propylene/propane splitter. The proposed method replaces other costly or long time methods for this purpose. Finally, two examples demonstrate the applicability of the proposed method in practice. Moreover, the extension of application area of the above method is showed.

Methodology of investigation

The adopted base design for entire study is a conventional distillation column for propylene/propane separation. The column feed composition is: 0.5 molar fraction propylene, 0.49 molar fraction propane and 0.01 molar fraction C4 hydrocarbons. Our study has been developed on the columns with 180, 200 and 240 actual sieve trays. The previous complete and compressive investigation demonstrates that the reflux flowrate has the most important factor that affects the thermal energy requirement of the conventional propylene/propane splitter, as well the polymer-grade propylene concentration [5]. Namely, at constant operating pressure, the increases in reflux flowrates conduct to an indesirable increase in SEC and SLPSC. But, the favourable effect of the reflux flowrates increasing emerges to a high purity degree of propylene product. In this opposite effect, the propylene concentration is the winner. Moreover, the operators of the propylene plants can handle this situation in two ways: firstly, in the existing propylene splitters the partial vaporization of the feed can decrease the energy consumption as was demonstrated in the second simulations step of this work; secondary (available only in the design of new plants), can accept splitters equipped with more stages which require less steam consumption as was demonstrated by all simulation steps performed in this work.

The compressive analysis develop in our research enabled us to obtain an important set of graphical correlations useful in practical purposes. For example, for a targeted polymer-grade propylene concentration (in range of 99.5 to 99.8 mole%) from above figures 5(b)-7(b) are depicted the proper optimum reflux flowrates for splitters containing 180 or 200 or 240 actual stages which are operated in range of 0.8 to 1.8 MPa. Next, from figures 5(a)-7(a) the SEC and SLPSC are estimated [5].

That the entire investigation developed in the first part of this work start at 40 tonnes per hour feed flowrate and 50 mole% propylene concentration in feed [5]. Our preoccupation was to extend the application area of above graphical correlation in order to cover a larger feed area. This is possible and will be demonstrated in two practical examples in the next section.

Extended area of application of graphical correlations

The objective of this section is to extend the applicability of above graphical correlations to a large area of feed flowrates. The most adequate way to understand the extension strategy is to assume two possible practical cases.

First case: a conventional distillation column is fed to 23 t per hour propylene/propane mixture with 50 mole% propylene. The feed liquid molar fraction is 0.2. It is assumed

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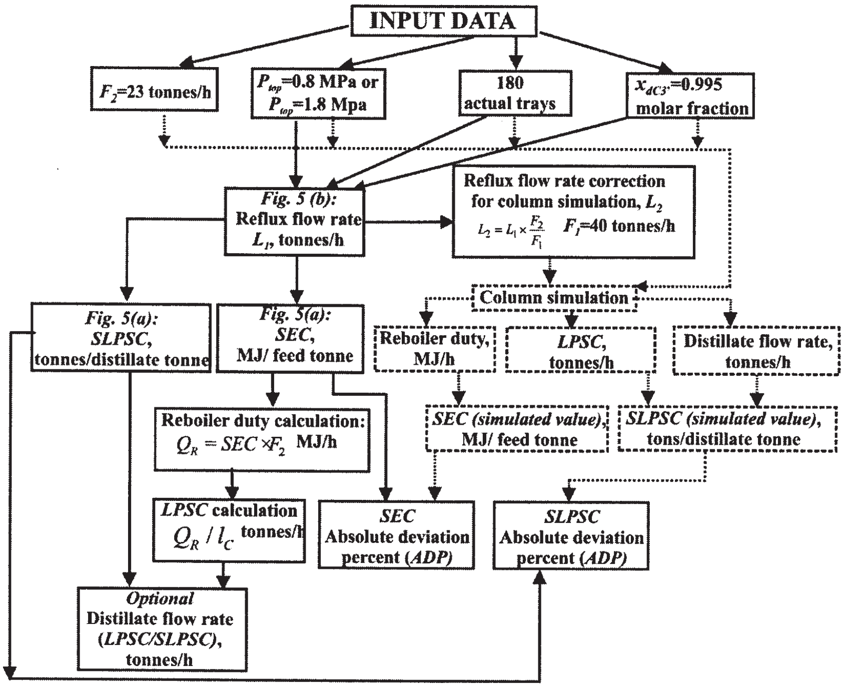

Fig. 1. The schematic procedure to solve the first practical case (dot lines symbolize the simulation flow connection, dash line symbolizes the simulation path flow and solid line symbolizes the graphical and calculation path flow)

Table 1

ERROR ANALYSIS AND ACCURACY OF GRAPHICAL CORRELATIONS IN COMPARISON WITH COMPUTATIONAL VALUES FOR THE FIRST PRACTICAL CASE

Pressure 0.8 MPa											
Graphical correlation values					Computational values					Absolute deviation percent (ADP)‡	
L1 from Fig. 5a, tonnes/h	SEC from Fig. 5b MJ/feed tonne	Q_R, MJ/h	LPSC, tonnes/h	SLPSC from Fig. 5b, tonnes/ distilate tonne	L2, tonnes/h	Q_R, MJ/h	SEC, MJ/ tonne feed	LPSC, tonnes/h	SLPSC tonnes/ distilate tonne	SEC	SLPSC
234	2050	47150	22.05	2.01	134.55	47085	2047.2	22.00	2.01	0.137	0.227
Pressure 1.8 MPa											
366	2651	60973	28.51	2.60	210.45	61127.2	2657.7	28.63	2.61	0.252	0.322

a 98% recovery of propylene. It was chosen a splitter equipped with 180 actual stages. The purpose of separation is 99.5 mole% propylene in the distillate product. What is the amount of SEC and SLPSC when splitter is operate at 0.8 MPa, respectively at 1.8 MPa?

Solution of first case:

To solve this practical case is useful to known only the heat of steam condensation. At thermal flow is assumed steam at 0.4 MPa and the heat of condensation (noted as l_c) is 2138.86 Mj/t. A schematic procedure is adopted to answer to the first question. Two parallel ways are described in the schematic procedure: the first one solves the first case based on above figure 5(a,b), the second is based on computer simulation with PRO/II Provision version 9.0 software [5]. In the end, an error analysis and accuracy of graphical correlations in comparison with computational values is done and the results are presented in table 1.

Figure 1 shows the schematic procedure to solve the first practical case. Supplementary, according to figure 1 it is possible to estimate the distillate flow rate. From simulation data is obvious obtaining the distillate flow rate.

From table 1 results a very good concordance between simulated values and those obtained from graphical correlation. It was also found that the most economical option for propylene/propane separation is the operating pressure by 0.8 MPa, as it is expected. But, for top vapour condensation is required frigorific agent. The availability of frigorific agent is the option of each propylene producer. If the refrigerant used is not an acceptable option, it can operate the propylene/propane splitter at 1.8 MPa pressure.

In the above described manner it might proceed to obtain the specific thermal consumption in another practical cases for polymer grade propylene concentration (in range of 99.5 to 99.8 mole%).

Second case: a conventional distillation column is fed to 44 t per hour propylene/propane mixture with 50 mole% propylene. The feed liquid molar fraction is 0.2. It is assumed a 98% recovery of propylene. The splitter is equipped with 240 actual stages. The purpose of separation is 99.6 mole% propylene in distillated product. An amount of 46 t per hour steam at low pressure (i.e. 0.4 MPa) is adequately to operating pressure at 1.6 MPa?

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‡ $(ADP)=\left|\frac{simulated\ values - graphycal\ values}{simulated\ values}\right| \times 100$

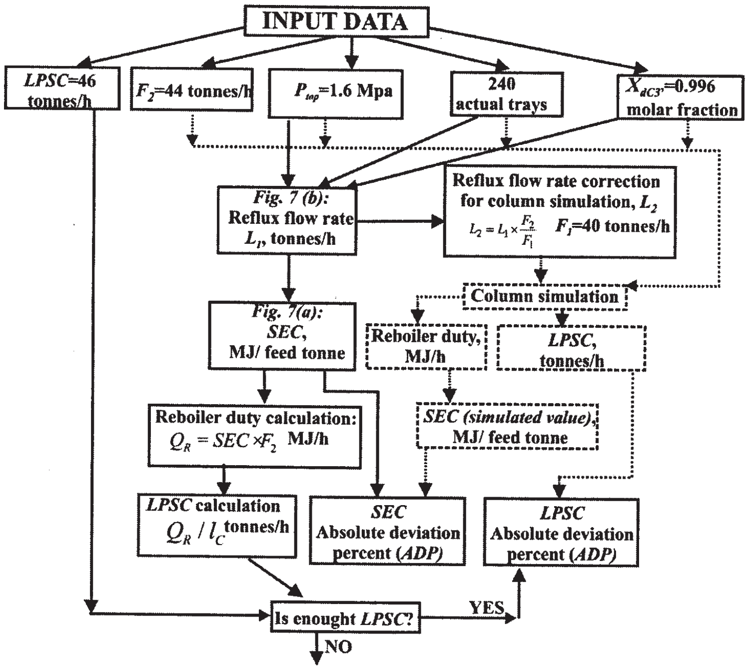

Fig. 2. The schematic procedure to solve the second practical case (dot lines symbolize the simulation flow connection, dash line symbolizes the simulation path flow and solid line symbolizes the graphical and calculation path flow).

Table 2
ERROR ANALYSIS AND ACCURACY OF GRAPHICAL CORRELATIONS IN COMPARISON WITH COMPUTATIONAL VALUES FOR THE SECOND PRACTICAL CASE

Graphical correlation values				Computational values				Absolute deviation percent (ADP)*	
L1 from Fig. 7a, tonnes/h	SEC from Fig. 7b, MJ/feed tonne	Q_R, MJ/h	LPSC, tonnes/h	L2, tonnes/h	Q_R, MJ/h	LPSC, tonnes/h	SEC, MJ/feed tonne	SEC	LPSC
296	2225	97900	45.77	325.5	97918	45.86	2225.41	0.0184	0.196

Solution of second case

The schematic procedure adopted to answer to the second question is shown in figure 2. As it is shown in the previous solved case, in parallel with graphical correlation from figures 7(a,b) runs a computer simulation calculation. Also, is it useful to known only the heat of steam condensation [5]. The error analysis and accuracy of graphical correlations in comparison with computational values are depicted in table 2.

From table 2 results a very good concordance between simulated values and those obtained from graphical correlation. It was also found that the 46 t per hour, low pressure steam is enough to provide the propylene/propane separation from 44 t per hour column feed.

The two practical cases presented in this paper section, allowed us to show the usefulness and the accuracy of the graphical correlations in evaluation of propylene/propane separation. Also it was proved that the graphical correlations developed in this work are able to substitute the computers simulations or other long time methods. Other benefits are the simplicity and availability of these correlations as tools to solve many practical cases.

Conclusions

This second part of our research is based on the graphical correlations outcomes from the complete and compressive analysis presented in the previous paper. It was considered that it is both theoretically and practically useful to know the connection between actual number of trays, operating pressure, thermal condition of feed flow, reflux flow rate, polymer grade propylene concentration in overhead product and thermal energy consumption of reboiler. As start point was selected a distillation column fed with 40 t per hour liquid at boiling point and a composition of: 0.5 mole fraction propylene, 0.49 propane molar fractions and 0.01 molar fractions C4 hydrocarbons. The three column configurations are considered and these are different of each other by actual number of stages, i.e. 180 or 200 or 240 sieve trays. The desired top product is polymer grade propylene (in range of 99.5 to 99.8 mole %). Propylene recovery in the top product is fixed at the 98%. The thermal energy consumption of reboiler was assumed in two distinct contributions, i.e. the specific energy consumption (noted as SEC) and specific low pressure steam consumption (noted as SLPSC).

The compressive analysis developed in this work enabled us to obtain an important set of graphical correlations useful in practical purposes. By coupling these correlations, results a simple and innovative graphical method with application in an extensive practical operating situations.

In this second part of our study it was demonstrated that our method is applicable in a large column feed area.

The proposed method successfully replaces other costly or laborious methods for the evaluation of thermal energy requirements for reboilers.

We expect that the proposed method represents a real benefit for the process engineers who may take rapid decisions on the efficient operation of the propylene/ propane splitters, depending on various practical cases, as well as a useful tool for new unit design or revamp of the existing ones.

References

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