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Energy saving in distillation columns: the Linde column revisited

Giorgio Soave[a], Laura Pellegrini[b], Davide Barbatti[b], Nicolò Susani[b], Susi Bonomi[b]

[a]*via Europa 7, S. Donato Milanese, Italy*
[b]*Politecnico di Milano, piazza Leonardo da Vinci 32, 20133, Milano, Italy*

Abstract

Linde double column is a smart device to separate gas mixtures without energy consumption at condenser and reboiler. The sections operate at different pressures to achieve a thermal integration in the middle of the whole tower, allowing energy savings that in the case of air separation are total. Calculations performed using Aspen Hysys® and Icarus® show that the same distillation scheme can be applied to other systems but sometimes it is necessary to add an auxiliary cooler that limits the advantage of the proposed scheme.

Keywords: distillation, energy saving, Linde column.

1. Introduction

Linde double column is a resourceful method to separate mixtures of gases reducing heat and cold consumptions: the main difference between a normal column and this equipment is that Linde column consists of two sections (columns), one on the other, that work at different conditions. The bottom column, that works at high pressure, is used to produce reflux for itself and for the second one; the pressure difference between the two columns is such that the heat produced in the reflux condensation of the bottom column can be used as heat source in the top column reboiler. The main variable to be calculated is the amount of reflux to the bottom column that can define the purity of the final products and the thermal charges needed in the exchangers.

An important case where Linde column is widely used is air separation, because critical proprieties of oxygen and nitrogen do not allow normal distillation; this process is an ideal case, because there isn't need to heat or to cool with auxiliary fluids. This complete energy saving can be attained only because air components have a particular combination of relative volatilities that fits very well for Linde system.

This paper will show how such a layout can be successfully applied to the separation of various hydrocarbon mixtures achieving important energy savings; sometimes however an external cooler is needed, which reduces in some way the economic advantage.

2. A simple example

In this paragraph it will be explained how to decrease, and, if possible, how to eliminate, on the basis of the Linde scheme, the condenser and reboiler thermal duties, that are the main source of operating costs for every kind of distillation. The explanation will refer to a particular system, chosen for its simplicity, containing only two light hydrocarbons, ethane and propane: it is a binary mixture whose components have the appropriate relative volatilities to make the separation so easy that the two columns have few ideal stages (~30). This statement is correct because the boiling points, calculated at atmospheric pressure, differ from one another of 47 K: for ethane the normal boiling point is 184.5 K, whereas it is 231.1 K for propane.

Three different cases were studied with Hysys®, corresponding to an ethane molar fraction in the feed of 50%, 60% and 70%. It can be remarked that the energy requests in the three cases have a different behaviour, because the richer in ethane is the mixture the easier the separation and the lower the energy required to keep the plant in operation. It is worth while underlining that there are only two heat exchangers in Linde configuration requiring another fluid, i.e. the reboiler of the high-pressure column and the condenser of the low pressure one; their duties can be substantially decreased and ideally brought to zero using the process simulator in the way reported here below.

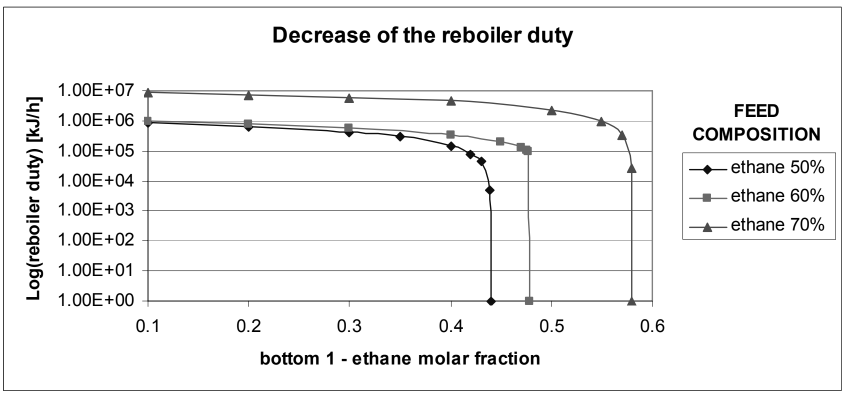

Fig. 1: Decrease of the reboiler duty versus bottom ethane content for various feeds.

At first we will discuss how to decrease the duty of the high-pressure reboiler: it can be cut down by increasing the molar fraction of ethane into the bottom product of the high pressure (column 1). Approaching a well-fixed concentration of ethane, which depends on the feed composition, the duty of the reboiler falls down to zero very quickly, as shown in Fig.1. That is to say that there is no need to have a bottom product very rich in propane (x_{B1}), because the separation is accomplished in the low-pressure column (column 2); for example, examining the feed with 70% of ethane, 58% of ethane as molar percentage into the bottom product is required in order to eliminate the reboiler, whereas almost all the propane present in the system is forced to stay in the bottom too, since the head product contains ethane at 99.9%.

While in case of high-pressure reboiler the problem has been solved with the simulator trying different values of the assigned variable (i.e. ethane molar fraction in the bottom) to reduce its duty, condenser thermal duty has been directly set to zero obtaining different outlet compositions in the three cases under study.

The result of this “no-duty” separation is not always satisfying, as can be seen in the following report (Table 1):

CASE	x_{D1}	x_{B1}	reboiler duty [kJ/h]	condender duty [kJ/h]	x_{D2}	x_{B2}
Ethane = 70%	0.999	0.58	0	0	0.9987	0.0056
Ethane = 60%	0.999	0.478	0	0	0.9566	0.0644
Ethane = 50%	0.999	0.44	0	0	0.8639	0.1426

Table 1: Ethane molar fraction in distillates (x_{D1}, x_{D2}) and bottoms (x_{B1}, x_{B2}).

Only in the case of 70% ethane feed a very good separation is achieved without energy supply, like air separation. A purity even better could be reached for a mixture ethane-propane which the most volatile component has a content higher than 70%.

In the case of ethane content less than 70% the engineer has to look for the best set of thermal duties that the plant needs to perform the required separation. In any case the adoption of Linde double column assures an important energy saving.

3. The industrial case

In the separation of ethane from propane the thermal integration is simply performed in the process flow diagram built up in Hysys® environment by means of two energy streams connecting the high-pressure condenser with the low-pressure reboiler, so that the reflux split is directly calculated by the simulator. Handling other mixtures the problem may arise of how to regulate the reflux streams, i.e. the system presents an additional degree of freedom.

This happens in another binary system, whose components are ethane and ethylene; it is known that the separation of the C2 fraction is much more difficult than ethane-propane one because the relative volatility is very low, around 1.2; this is proved by the great energy consumption (Peters and Timmerhaus, 1980) and by the height (not less than 100 theoretic stages) of the towers used for this separation. The process flow diagram for C2 separation by means of Linde process is a more complex one, as shown below in Fig. 2:

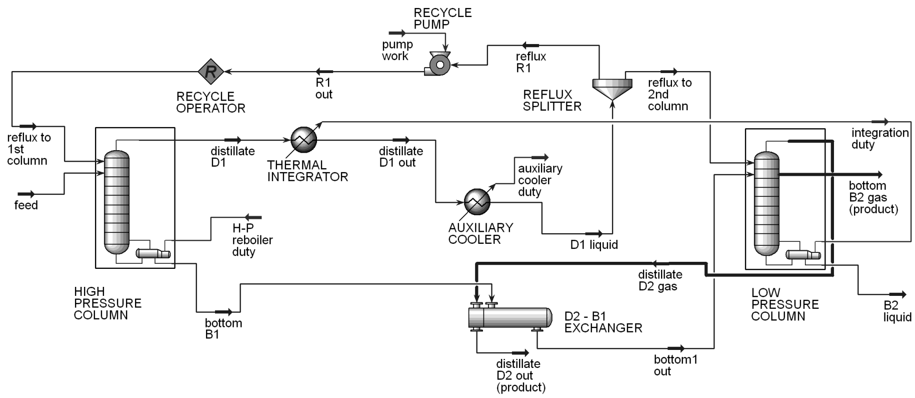

Fig. 2: Hysys® process flow diagram for ethane-ethylene separation.

It has been built up in Hysys® simulation environment using two columns which have only the reboiler: at first the thermal duty of the high pressure exchanger is minimized, whereas in the second column (low pressure) the thermal integration is simulated by linking the duty of an external cooler (*thermal integrator*) to the low pressure reboiler. Following the route of the streams it can be seen that *distillate D1* is condensed in two stages and then is split in order to create the liquid refluxes for the columns; before entering the low pressure column the *bottom B1* flows into an exchanger (*D2–B1 exchanger*) which allows to recover some energy from *distillate D2 gas*. The final products are two gaseous streams coming out from the *low pressure column*: *bottom B2 gas* and *distillate D2 out*. Some details about the columns are shown in Table 2 (ethane and ethylene are respectively 15.24% and 84.76% on molar basis in the feed):

	TRAY NUMBER	FEED ENTRANCE	TEMPERATURE [K]	TOP PRESSURE [bar]	BOTTOM PRESSURE [bar]
COLUMN 1	40	tray 35	196 – 202	4	4.2
COLUMN 2	60	tray 35	172 – 191	1.2	1.44

Table 2: Double column features.

The determination of the best reflux split is possible with Hysys®: fixing the step size and lower and upper bounds for the independent variable, so that outputs are calculated and registered every time that inputs are changed, the optimum problem can be solved. If the variable is the split ratio, defined as the ratio between the molar flow of the reflux to high pressure column and the molar flow of *D1 liquid* (equal to the sum of refluxes), the simulator is able to determine his optimum value (about 0.65), i.e. the value in correspondence to which the system requires less energy to condense the stream D1 and in the meantime the products present a high purity, reaching 99.95% of ethylene in *distillate D2* and 100% ethane in *bottom B2*. Anyway there are some residual thermal duties that cannot be removed without making the separation worse.

In order to quantify the obtained results the value of the energy consumed according to the Linde approach has been compared with the consumptions for the single tower (100 ideal stages, i.e. 60+40) scheme, with the same operating conditions and the same purity in the outlet streams. Two levels of working pressure have been considered: 4 bar and 20 bar. From the comparative analysis it results that the adoption of the Linde tower allows large energy savings in both the cases (Table 3):

	4 BAR TOWER	**20 BAR TOWER**
Heat Saving	53,1%	70,5%
Cold Saving	58,4%	71,8%

Table 3: Savings (percentages) adopting Linde double column.

The calculation refers to the power values expressed in kJ/h, obtained by Hysys® during the research for the optimum, but this comparison does not face the thermal level of the exchange: the operating costs associated to heat removal at about 200 K are very different from those for the same operation at 270 K; this is the main reason for using another simulator, Icarus®, that can perform a complete profitability analysis taking into account both fixed and operating costs.

In the case under study the distinguishing feature is the cost of the cooling and heating fluids: for Linde column and the 4-bar single column the cooler works at about 163 K, so liquid ethane at atmospheric pressure is necessary as coolant, with a cost of about 20$/GJ (Turton, 2003); on the contrary heating has a very lower cost, because supplying heat at 213 K is not a problem (it is assumed to be free of charge). For the single column working at 20 bar it is necessary a coolant at about 233 K, e.g. liquid propane, whereas the reboiler process fluid has a temperature little below 273 K, and so water can be used as heat source. Under these hypotheses Icarus® can collect data from Hysys® and estimate costs (Table 4):

	Capital costs (M$)	**Operating costs (M$/year)**	**Utilities costs (M$/year)**
LINDE	6.851	4.543	3.000
4 BAR TOWER	7.382	8.944	7.222
20 BAR TOWER	8.589	8.670	6.909

Table 4: Estimated costs from Icarus®.

Savings are evident, because capital costs for Linde tower are lower and in the meantime operating cost are almost halved; it is useful to analyse the utilities cost term, because it constitutes the main part of the operating costs and more or less represents the same percentage of operating cost for all the cases studied.

4. Conclusions

After studying different systems, we can assert that Linde tower allows important energy savings in separation of mixtures that present the following features:

1. binary system are preferred, because it is easier to have the appropriate temperature difference needed for the thermal integration between the sections; in case of multicomponent mixture it is better having two prevalent components, so that the system can be similar to a binary one;
2. even if usually separation is promoted by high relative volatility, for Linde device this shouldn't be too different, otherwise the integration becomes more difficult;
3. the most volatile components should have higher content than the others.

The combination of all the three options is summed up in the two previously quoted mixtures, i.e. air and ethane-propane with ethane content higher than 70%; this is the reason why it is possible to perform a separation without external exchangers, which means cutting down the operating costs. Anyway, whereas the air separation by Linde method is really applied, it is not the case of ethane-propane, since it does not represent a separation of industrial interest.

At the end we can say that the we have proved the profitability of Linde concept applied to C2 separation, but we should extend the analysis considering that usually ethane-ethylene separation is achieved in a tower operating over 20 bar, along a distillation train into oil refinery plants and that the industrial coolant is the head product, after expansion, of the subsequent column.

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