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INVESTIGATION OF MATERIAL COST OF AN ETHANE-ETHYLENE RECTIFICATION COLUMN

Viktória Kállai
assistant research fellow, University of Miskolc, Institute of Energy Engineering and Chemical Machinery
3515 Miskolc, Miskolc-Egyetemváros, e-mail: viktoria.kallai@uni-miskolc.hu

Péter Mizsey
professor, University of Miskolc, Institute of Chemistry
3515 Miskolc, Miskolc-Egyetemváros, e-mail: kemizsey@uni-miskolc.hu

Gábor L. Szepesi
associate professor, University of Miskolc, Institute of Energy Engineering and Chemical Machinery
3515 Miskolc, Miskolc-Egyetemváros, e-mail: gabor.szepesi@uni-miskolc.hu

Abstract

In this study with the tray-by-tray method an ethane-ethylene rectification column was studied. Therefore, the effect of reflux ratio on the material cost of ethane-ethylene rectification column was investigated. In case of the modification of reflux ratio the diameter of the column and the number of trays will modify. Not only these parameters, but also the required wall thickness for strength was determined. In case of the investigated column between the reflux ratio and the diameter of the column there is second degree polynomial relationship. There is a minimum point of the material cost function, which belongs to the optimal reflux ratio.

Keywords: *reflux ratio, material cost, ethane-ethylene rectification column*

1. Introduction

The ethylene is product and feedstock of the chemical industry, the double bond of the ethylene makes it industrially convertible to a variety of intermediate and end products. (Benali and Aydin, 2010). From ethylene polyethylene is produced by polymerization, and this is the raw materials of numerous plastic, paper and textile products. It is important to produce this in large quality and quantities. The two components are difficult to separate because of their similar physical behaviour and properties. For the ethane-ethylene separation the widespread technology is the so-called cryogenic distillation, it is a very energy and cost-intensive procedure (Liao et al., 2015; Shi et al., 2010).

The reflux ratio is an important parameter not only in terms of the purity of the overhead product but also in terms of the diameter, the number of trays and the costs of the column.

2. The method of the investigation

Firstly, with the so-called tray-by-tray calculation method (Földes and Fonyó, 1978) the theoretical number of trays were determined in case of different values of reflux ratio. From this calculation the mass flow of the vapour and liquid streams in the column, the mole fraction of the light component in the bottom product were given. The essence of the method is that the system of equations that can be written for the column is solved tray-by-tray. The calculation is started at one (or both) ends of the column, where the stream and composition values are assumed, and then using this data, to move on the next tray. According to the approximation methods, all trays are counted in one iteration (Földes and Fonyó, 1978).

During the tray-by-tray calculation ethane and ethylene components were treated as ideal ones, because from their equilibrium diagram it is shown that between the SRK and ideal equations of state there is lower difference than 5% (Figure 1.). The lower the pressure, the smaller the deviation from the ideal case.

In the Figure 1. x is the mole fraction of ethylene in the liquid phase and y is the mole fraction of ethylene in the vapour phase.

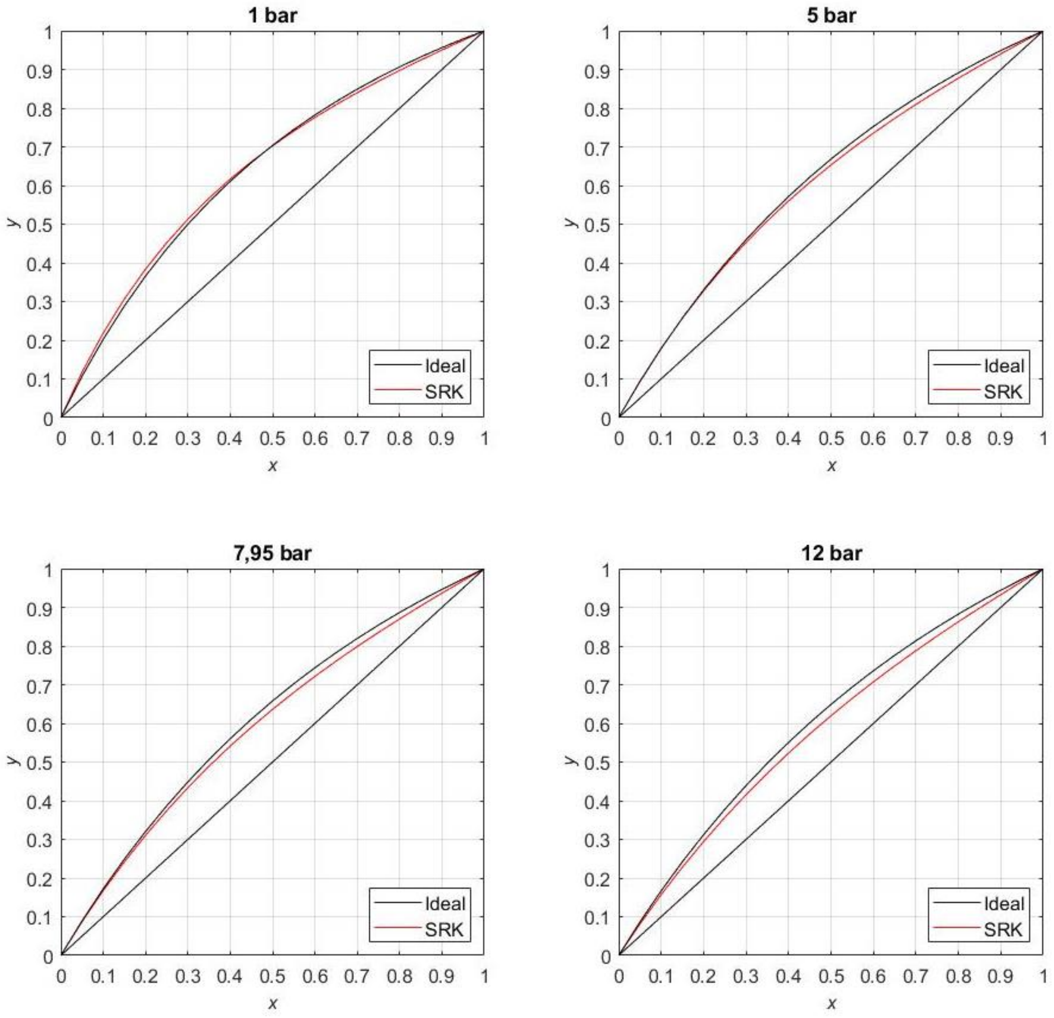

Figure 1. *Equilibrium diagrams at different pressures*

From the determined data with the so-called Souders-Brown-Fair method the diameters of the columns were calculated. In this case it is necessary to use the Fair diagram (Figure 2.), during this study the tray spacing was 0.457 m in both investigated columns (Fonyó and Fábry, 1998, Perry, 1950).

For this calculation the density of the liquid and vapour streams, the surface tension of the liquid stream should be known. In this study these parameters were determined by UniSim Design® (UniSim Design, 2009) process simulator software with SRK equation of state (Jaubert and Privat, 2010). This equation of state is appropriate for the investigation of carbohydrates in high pressure and in low temperature (Némethné, 2013).

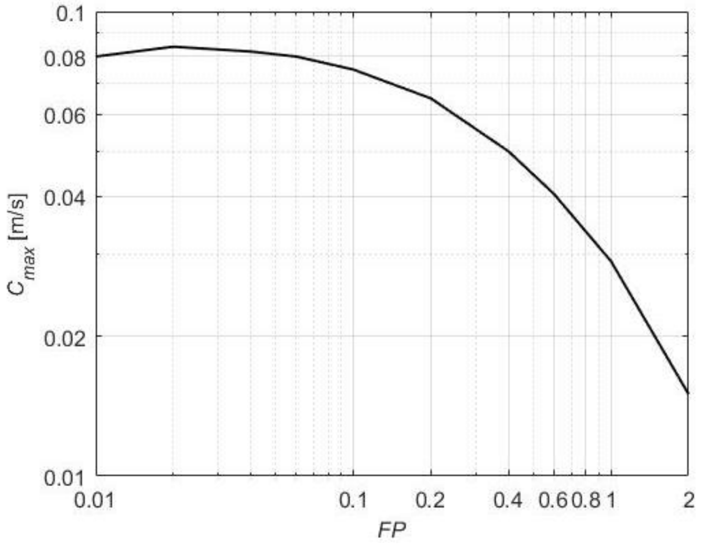

Figure 2. *Fair load capacity diagram (Fonyó and Fábry, 1998; Perry, 1950)*

In the Figure 2. the *FP* parameter is the flow parameter, it should be calculated with the following equation:

$$FP = \frac{L}{V} \cdot \sqrt{\frac{\rho_V}{\rho_L}}, \tag{1}$$

where L is the liquid stream inside the column [kg/h], V is the vapour stream inside the column [kg/h], ρ_V is the density of the vapour phase [kg/m^3], ρ_L is the density of the liquid phase [kg/m^3].

The diagram is used to determine the maximum vapour velocity for flooding using the Souders-Brown-Fair method:

$$v_{max} = C_{max} \cdot \left(\frac{\sigma}{0.02}\right)^2 \cdot \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}, \tag{2}$$

where v_{max} is the maximum vapour velocity for flooding [m/s], C_{max} is the capacity parameter [m/s], σ is the surface tension of the liquid phase [N/m].

The allowable vapour velocity (v_a [m/s]) is 70% of maximum vapour velocity:

$$v_a = 0{,}7 \cdot v_{max} \tag{3}$$

The cross-section of the tray can be determined by taking into account the internal vapour flow rate and the allowable velocity:

$$A_t = \frac{V_V}{v_a}, \tag{4}$$

where A_t is the surface of a tray [m^2], V_V is the internal vapour flow rate [m^3/s].

Due to the downcomer, a 1.2 times allowance is required to determine the cross-section of the column:

$$A_c = 1.2 \cdot A_t, \tag{5}$$

where A_c is the cross-section of the column [m^2]. Thus, the diameter of the column (D [m]) can be determined:

$$D = \sqrt{\frac{A_c \cdot 4}{\pi}}. \tag{6}$$

Furthermore, a strength calculation was used to determine the wall thickness required for the column with the given operating parameters. These calculations based on the standards of MSZ-EN 13445-3 and MSZ-EN 10028-7.

As the reflux ratio increases, the required number of trays decreases to reach the given purity of the overhead product and the diameter of the column increases, which will increase the required wall thickness. Taking these changes into account, it was determined how the material cost of a given column changes with increasing reflux ratio when using 1.4404 austenitic steel.

The thickness of the trays was 5 mm, so the volume of a tray can be determined by the following equation:

$$V_t = A_t \cdot t_d, \tag{7}$$

where V_t is the volume of a tray [m^3], t_d is the thickness of a tray [m].

The density of the chosen steel is 8000 kg/m^3. The mass of a tray is given by its volume and density:

$$m = V_t \cdot \rho_{st}, \tag{8}$$

where m is the mass of a tray [kg] and ρ_{st} is the density of the chosen steel [kg/m^3].

During this study only the column's part with trays was investigated, thus the height of the column is calculated with the following equation:

$$H = N_t \cdot t_d + (N_t - 1) \cdot t_t, \tag{9}$$

where H is the height of the column [m], N_t is the theoretical number of trays, t_t is the tray spacing [m].

Knowing the wall thickness and height of the column, its volume can be determined using the following equation:

$$V_c = \left(\frac{D_e^2 \cdot \pi}{4} - \frac{D_i^2 \cdot \pi}{4}\right) \cdot H, \tag{10}$$

where V_c is the volume of the column [m^3], D_e is the external diameter of the column [m], D_i is the internal diameter of the column [m].

Knowing the parameters described above, the material costs of trays and columns can be determined. The price of the material (1.4404 austenitic steel) was determined according to the referenced website (http://www.estainlesssteel.com/usstainlesssurcharges.shtml., 2022.04.26).

3. The investigated systems

3.1. Ethane-ethylene rectification column

In Table 1. the parameters of the feed and products of the ethane-ethylene column are summarized.

Table 1. *The parameters of the feed and the products of the ethane-ethylene rectification column*

	Feed	Distillate	Bottom product
Temperature [°C]	-55.00	-60.50	-41.62
Pressure [bar]	7.95	7.45	7.45
Mass flow [kg/h]	53750	44252	9498
Ethylene [mole%]	83.30	99.95	0.17
Ethane [mole%]	16.70	0.05	99.83

In Figure 3. the effect of increasing the reflux ratio on the number of trays and the diameter of the column was plotted. The relationship between reflux ratio and column diameter can be described by the following second-degree polynomial function:

$$D = -0{,}0203 \cdot R^2 + 0{,}7139 \cdot R + 2{,}8407. \tag{11}$$

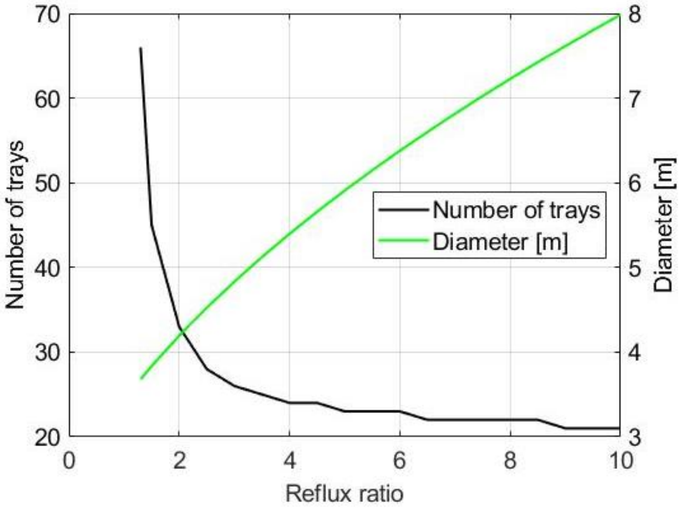

Figure 3. *Effect of the reflux ratio on the number of trays and the diameter of ethane-ethylene column*

Figure 4. shows the relationship between the reflux ratio and the material cost of the trays and the ethane-ethylene separation column. The diagram shows that the optimum value of the reflux ratio from the material cost's point of view is 2.5.

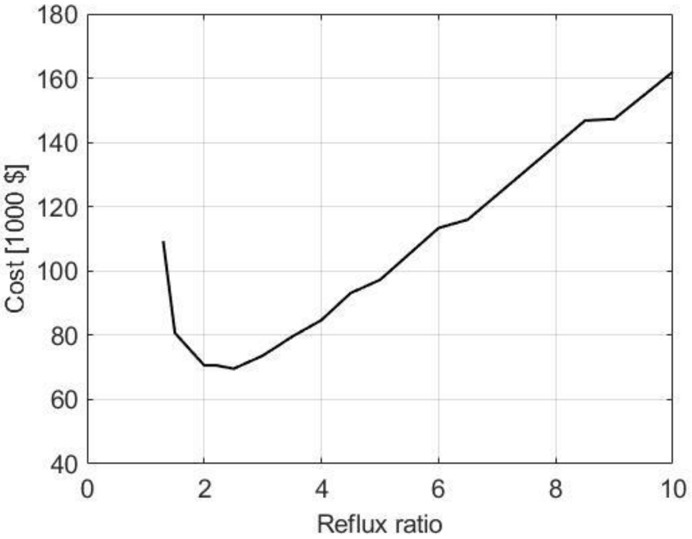

Figure 4. *The effect of the reflux ratio on the material cost of the ethane-ethylene distillation column*

3.2. Comparison of cost functions with the literature

J. M. Douglas (Douglas, 1998) demonstrated equipment's costs functions, from these the purchased cost of columns is determined with the following function:

$$PC = \frac{M\&S}{280} \cdot 101.9 \cdot D^{1.066} \cdot H^{0.82} \cdot F_c, \tag{12}$$

where *M&S* is the Marshall and Swift cost index [-], its value was 2171.6 in 2020 (Camaraza-Medina et al., 2020). In the (12) equation *D* is the diameter of the column [ft], *H* is the height of the column [ft] and F_c is determined with the following equation:

$$F_c = F_m \cdot F_p, \tag{13}$$

where F_m is the factor which consider the quality of the material [-], in case of the chosen stainless steel its value is 3.67, F_p is the factor which take into account the pressure of the column, in case of the studied ethane-ethylene distillation column it is 1.065.

In the Figure 5. the purchased and material costs of the investigated column are demonstrated. The material cost includes only the price of the material for the column, while the literature context gives the total purchase cost of the column. In case of ethane-ethylene in both cases the cost functions have a minimum point, where the reflux ratio's value is 2.5. It can be concluded that within the studied reflux ratio interval, the ethane-ethylene column's material cost is on average 13.53 times lower than the total purchased cost of the column.

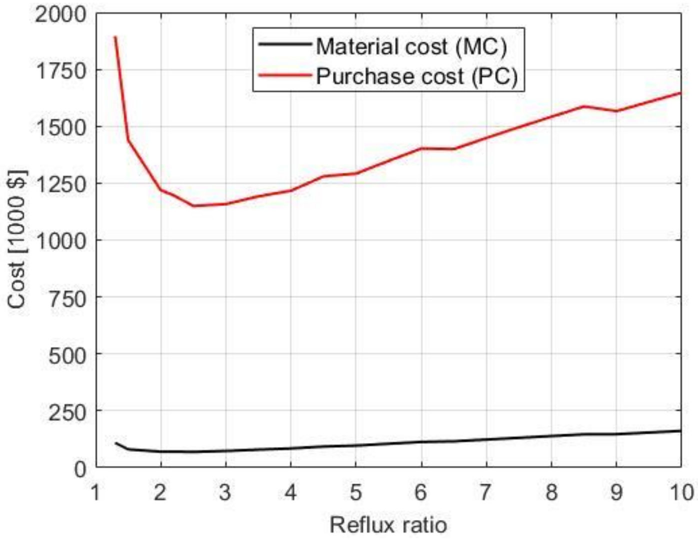

***Figure 5.** Costs as a function of reflux ratio for ethane-ethylene column*

4. Summary

In this study an ethane-ethylene distillation column was investigated by tray-by-tray calculation method. Furthermore, the modification of reflux ratio was studied to determine the diameter and material costs of the column in case of using 1.4404 austenitic steel. Comparing the results with literature correlation results of purchased cost, it can be concluded that the purchased costs from the literature and the calculated material costs have the similar nature. It can be found that within the studied reflux ratio interval, the material cost of the investigated ethane-ethylene column is on average 13.53 times lower than the total column purchase cost.

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