

# Influence of the Gas Phase Non-Ideality on the Efficiency of a Distillation Column

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Received: 📅 2025 Dec 15

Accepted: 📅 2026 Jan 03

Published: 📅 2026 Jan 17

## Abstract

The objective of this research is to study the influence of the non-ideality of the gas phase on the efficiency of a binary continuous distillation column. The column is loaded with a binary liquid mixture. The study is carried out by simulation. The study is carried out in order to highlight the influence of the non-ideality of gas phase on the performance of a binary continuous distillation column. A comparative study was performed in the case of an ideal and non-ideal behaviour of the gas phase occurs. The results obtained show the possibility of separation of the two components even in the case of the non-ideality behaviour of the gas phase despite the use of a great number of trays.

**Keywords:** Non-Ideality, Distillation, Simulation, Column, Tray, Separation

## 1. Introduction

This research focuses on the influence of the non-ideality of the gas phase on the performance of a continuous distillation operation. The distillation process is very used in the industrial practice for the production of various and important chemicals [1-3]. The operation of the continuous distillation presents many challenges, such as a strong dependence of distillate concentration products on the operative conditions [3-4]. The occurrence of behaviour deviation from the ideality of the gas phase can also have detrimental consequence on the column design and, consequently, on the separation quality. It's important to notice that the gas phase is more subject to non-ideality than the liquid phase. The behaviour deviation from the ideality of the gas phase is due to high or excessive operative temperature and pressure inside the column. These considerations motivate the need for highlighting the effect of the non-ideality on the efficiency of a continuous binary distillation column. For this purpose, the mathematical model of the liquid- vapor equilibrium was considered and solved using the data related to a nominal case [5-6]. Afterwards, a comparison study was carried out between an ideal and a non-ideal gas phase behavior in order to illustrate the influence of the gas phase non-ideality on the performance of a continuous binary distillation column.

## 2. The Liquid –Non-Ideal Vapor Equilibrium Models

The fugacity of chemical specie expresses the difference between its properties in a neat state and in a real mixture. The concept of fugacity is applicable for gases, liquids and even solids. The fugacity allows the calculus of the phase equilibrium. The fugacity (F) is determined as a function of

pressure (P) and fugacity coefficient ( $\nu$ ) as follows.

$$F = P \cdot \nu \quad (1)$$

In the case for which the gas phase possesses an ideal behavior, the equilibrium curve is computed from the following expression.

$$y = \alpha / [(\alpha - 1) \cdot x + 1] \quad (2)$$

In the previous equation, y is the molar fraction in the gas phase of the more volatile component and x is the molar fraction in the liquid phase of the more volatile component,  $\alpha$ , is the mean relative volatility, it represents the ratio of the saturation pressure of the more volatile component to the least component one for a constant temperature ( $\alpha = P_{s_A} / P_{s_B}$ ). In the case for which the gas phase possesses a non-ideal behavior, in order to determine the equilibrium curve, the following equations are used for the determination of the molar fraction in the liquid phase ( $x_A$ ) and in the gas phase ( $y_A$ ) of the more volatile component (A).

$$x_A = F_A^G \cdot (F_B^G - F_B^L) / [F_B^G \cdot F_A^L - F_B^L \cdot F_A^G] \quad (3)$$

$$y_A = x_A \cdot F_A^L / F_A^G \quad (4)$$

In the previous equations,  $F_A^G$  means the fugacity of component A in the gas phase,  $F_A^L$  means the fugacity of component A in the liquid phase. Also,  $F_B^G$  means the fugacity of component B in the gas phase and  $F_B^L$  means the fugacity of component B in the liquid phase. The abacus of HOUGEN

and WATSON gives the fugacity coefficient ( $\nu$ ) for gases as a function of reduced temperatures ( $T_r$ ) and reduced pressures ( $P_r$ ). So, the determination of the fugacity requires the determination of the corresponding saturated pressure

( $P_{s,r}$ ), the corresponding reduced saturated pressure ( $P_{s,r}$ ), the critical temperature ( $T_c$ ), and the critical pressure ( $P_c$ ) of the component.

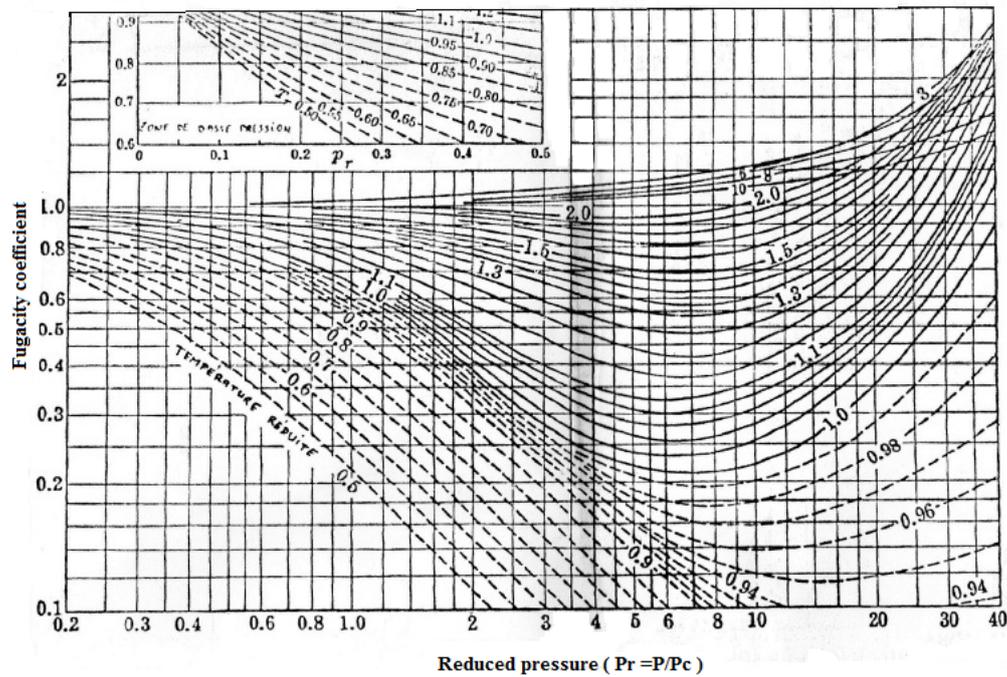


Figure 1: Hougén and Watson Abacus Used for the Determination of Fugacity Coefficient [7]

T (°C)	-18	--20	-22	-24	-26	-28	-30	-32	-34	-36
$Tr^{(1)}$	0,903	0,898	0,888	0,882	0,874	0,867	0,860	0,852	0,845	0,838
$P_{sA}$	27	25,6	24,4	23,2	22	20,8	19,8	18,7	17,6	16,8
$(P_{sA})_r$	0,533	0,505	0,482	0,458	0,435	0,412	0,391	0,369	0,348	0,332
$\nu_A^L$	0,74	0,75	0,755	0,760	0,765	0,780	0,785	0,790	0,800	0,805
$F_A^L$	20	19,2	18,4	17,65	16,85	16,2	15,55	18,8	14,1	13,55
$Pr$	0,318	0,318	0,318	0,318	0,318	0,318	0,318	0,318	0,318	0,318
$\nu_A^G$	0,85	0,85	0,84	0,84	0,84	0,84	0,83	0,83	0,82	0,82
$F_A^G$	13,6	13,6	13,4	13,4	13,4	13,3	13,3	13,3	13,2	13,1

Table 1: Fugacity ( $F_A$ ) and Fugacity Coefficient ( $\nu_A$ ) of Ethylene (Component A) in the Gas and Liquid Phases as a Function of Temperature (T)

T	-18	--20	-22	-24	-26	-28	-30	-32	-34	-36
$Tr$	0,825	0,820	0,812	0,806	0,800	0,792	0,786	0,780	0,774	0,767
$P_{sB}$	15	14,2	13,5	12,8	12	11,3	10,7	10	9,4	8,9
$(P_{sB})_r$	0,312	0,229	0,280	0,266	0,250	0,235	0,222	0,208	0,195	0,185
$\nu_B^L$	0,80	0,81	0,81	0,82	0,82	0,83	0,83	0,84	0,84	0,85
$F_B^L$	12	11,5	10,9	10,5	9,85	9,40	8,90	8,40	7,90	7,55
$Pr$	0,332	0,332	0,332	0,332	0,332	0,332	0,332	0,332	0,332	0,332
$\nu_B^G$	0,79	0,79	0,78	0,78	0,77	0,77	0,76	0,76	0,75	0,75
$F_B^G$	12,64	12,6	12,5	12,5	12,3	12,3	12,1	12,1	12	12

Table 2: Fugacity ( $F_B$ ) and Fugacity Coefficient ( $\nu_B$ ) of Ethane (Component B) in the Gas and Liquid Phases as a Function of Temperature (T)

x	0,0915	0,175	0,255	0,335	0,430	0,520	0,630	0,740	0,830	0,920
y	0,135	0,247	0,350	0,440	0,555	0,630	0,730	0,820	0,890	0,950

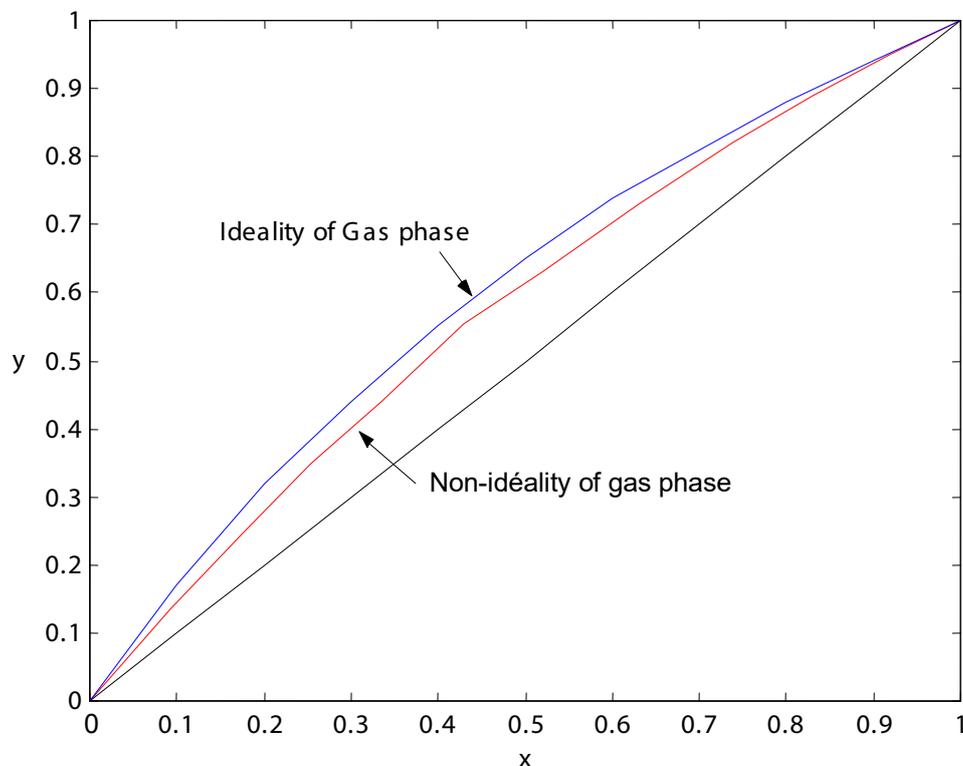
**Table 3: Equilibrium Curve for Ethylene- Ethane Binary Mixture Having a Non-Ideal Behavior in Gas Phase**

x	0.1	0.2	0.3	0.4	0.5	0,520	0,6	0,7	0,8	0.9
y	0,170	0,320	0,440	0,440	0,550	0,630	0,740	0,810	0,880	0,940

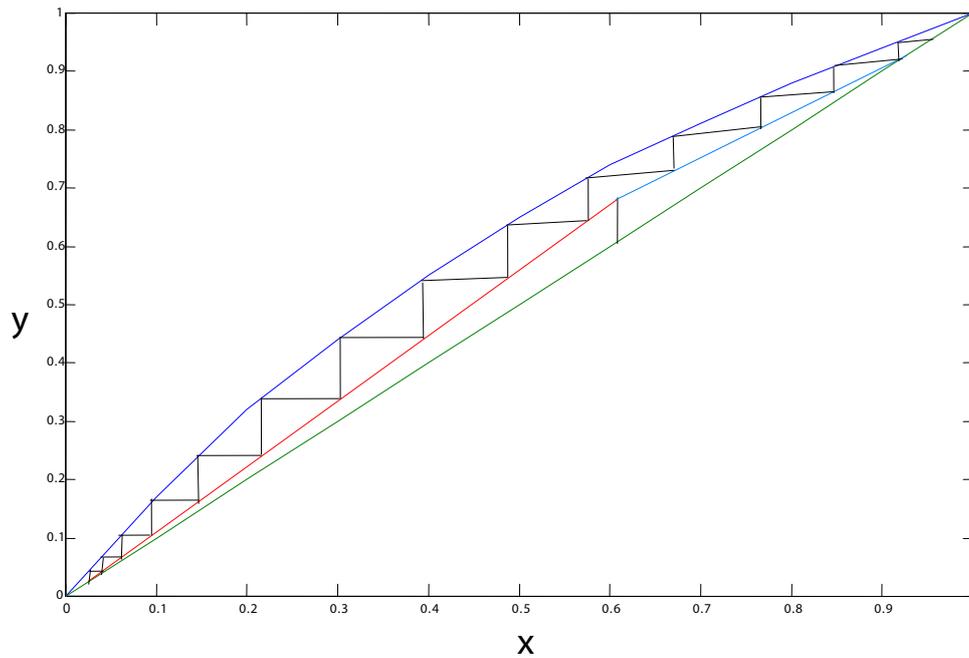
**Table 4: Equilibrium Curve for Ethylene- Ethane Binary Mixture Having an -Ideal Behavior in Gas Phase**

In this study, ethylene and ethane binary mixture is to be distilled in a continuous column at relatively high pressure ( $P = 16 \text{ atm.abs}$ ). From scientific literature it was found that ethylene has a critical temperature and pressure equal, respectively to  $9.6 \text{ }^\circ\text{C}$  and  $50.7 \text{ atm}$  ( $T_{c_A} = 9.6 \text{ }^\circ\text{C}$ ;  $P_{c_A} = 50.7 \text{ atm.abs}$ ) [8]. The ethane has a critical temperature and pressure equal, respectively to  $36.3 \text{ }^\circ\text{C}$  and  $48.2 \text{ atm}$  ( $T_{c_A} = 36.3 \text{ }^\circ\text{C}$ ;  $P_{c_A} = 48.2 \text{ atm.abs}$ ). By using equation (1) the fugacity coefficient and fugacity of ethylene and ethane in the gas and liquid phases were determined and the obtained results are presented in Tables 1 and 2. By using equation (1), (3) and (4), the liquid- vapor equilibrium curve was calculated in the case of non-ideal behavior of the gas phase and the obtained results are presented in table 3. By using equation (2), the liquid- vapor equilibrium curve was calculated in the case of an ideal behavior of the gas phase and the obtained results are presented in table 4. Fig 2 shows the liquid-vapor equilibrium curves of Ethylene-Ethane binary mixture in the case of the ideality and non-ideality of the gas phase. It can be noticed from fig 2 that the equilibrium curve in the

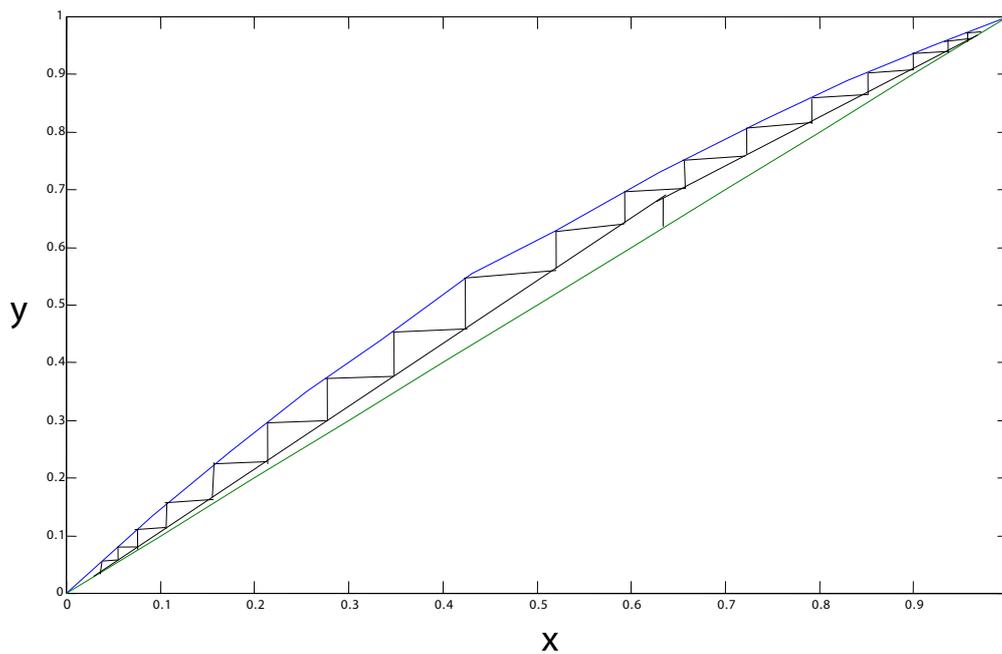
case of non-ideality of gas phase is closer to the first bisector relatively to the case of an ideality of the gas phase. The continuous binary distillation is assumed to be carried out with a feed stream at its boiling point having a molar fraction of ethylene ( $z_A$ ) equal to 0.64. The desired molar fraction of ethylene in the distillate is equal to 0.97 ( $x_{DA} = 0.97$ ), and the desired molar fraction of ethylene in the residue is equal to 0.03 ( $x_{DA} = 0.03$ ). The graphical method of McCabe-Thiele was applied in the case of ideality (fig 3) and non-ideality behavior of gas phase (fig 4). In these figures, the required number of trays to carry out the separation is expressed by the number of steps or horizontal lines between the equilibrium curves and the operative lines in the enrichment and impoverishment section of the distillation column. Fig 3 shows that in the case of ideality of the gas phase, the number of necessary trays is equal to 14, on the other hand fig 4 shows that in the case of non-ideality of the gas phase, the number of necessary trays is equal to 18. So, the non-ideality of the gas phase causes an increase of the required tray number to carry out the distillation.



**Figure 2: Liquid -Vapor Equilibrium Curves of Ethylene-Ethane Binary Mixture in the Case of Ideality and Non-Ideality of the Gas Phase**



**Figure 3: McCabe-Thiele Graphical Method for Ethylene-Ethane Binary Mixture in the Case of Ideality of the Gas Phase (Feed Stream at its Boiling Point Having a Composition:  $Z_A = 0.64$ )**



**Figure 4: McCabe-Thiele Graphical Method for Ethylene-Ethane Binary Mixture in the Case of Non-Ideality of the Gas Phase (Feed Stream at its Boiling Point Having a Composition:  $Z_A = 0.64$ )**

### 3. Conclusions

This work highlighted the influence of the non-ideality of gas phase on the efficiency of continuous binary distillation operation. It was showed that the non-ideality of the gas phase provokes the increase of required tray number of the distillation column relatively to the case for which the gas phase has an ideal behavior. As a consequence, if possible, it would be better to operate the distillation at low pressure and temperature in order to avoid the occurrence of the non-

ideality of the gas phase, otherwise the distillation column will be undersized for the desired separation. In a future work, the influence of the simultaneous non-ideality of both gas and liquid phases will be studied.

### References

1. Rejl, F., Valenz, L., Haidl, J., Moucha, T., Cmelikova, T., & Petricek, R. (2018). Novel model for separation efficiency of packed distillation columns. *Chemical Engineering*

- Transactions*, 69, 67-72.
2. C. Bendjaouahdou, Influence of Operating Parameters on the Efficiency of a Multi Components Flash Distillation Operation, Preprints.org, 1,2024, 1-6.
  3. Bendjaouahdou, C. (2024). Parametric study of a ternary batch distillation column. *Research Square* (<https://doi.org/10.21203/rs.3.rs-5427642/v1>), 1(1), 14.
  4. Ferris, A. M., & Rothamer, D. A. (2016). Methodology for the experimental measurement of vapor-liquid equilibrium distillation curves using a modified ASTM D86 setup. *Fuel*, 182, 467-479.
  5. Sharma, A., Drgoňa, J., Ingole, D., Holaza, J., Valo, R., Koniar, S., & Kvasnica, M. (2016). Teaching classical and advanced control of binary distillation Column. *IFAC-PapersOnLine*, 49(6), 348-353.
  6. Pirola, C. (2019). Learning distillation by a combined experimental and simulation approach in a three steps laboratory: Vapor pressure, vapor-liquid equilibria and distillation column. *Education for Chemical Engineers*, 28, 54-65.
  7. MacDougall, F. H. (1944). Chemical Process Principles. Part One: Material and Energy Balances. By Olaf A. Hougen and Kenneth M. Watson. *The Journal of Physical Chemistry*, 48(4), 232-232.
  8. J. H. Perry, chemical engineering handbook, fifth edition, Mc graw-Hill, New York, 1973.