Analysis of the zone connecting consecutive sectors in distillation columns by the Ponchon–Savarit method

A. Marcilla, M.D. Serrano and J.A. Reyes-Labarta.*
Dpto. Ingeniería Química, Universidad de Alicante, Apdo. 99, Alicante 03080, Spain.
Telf. (34) 965 903867 Fax (34) 965 903826. e-mail: a.marcilla@ua.es
http://iq.ua.es/gcef.htm

Summary

McCabe-Thiele [1] and Ponchon-Savarit [2] methods are two classical graphical methods for the design of binary distillation columns very useful for didactical purposes and for preliminary calculations. Nevertheless, their description in the literature is not complete and not all the cases are analysed. A previous paper [4] dealt with McCabe-Thiele and this work focuses on the Ponchon-Savarit method. A consistent analysis of what may happen when in the zone connecting consecutive sectors in the column (ZCCS) is presented for any feed condition, together with the different possibilities to extract products or to add or remove heat.

Differences between the classical and ZCCS analysis

When a feed stream is considered (GF_k), whatever its physical condition, it is commonly assumed to be introduced to a single tray (k+1,1 in Fig. 1a) where it mixes with the vapour of the tray below (k+1,2) and with the liquid of the tray above (k,NTk). The streams leaving this feeding stage ($L_{k+1,1}$ and $V_{k+1,1}$) are considered to be in equilibrium and the separation between the liquid (L_{GFk}) and vapour (V_{GFk}) portions is considered to have a small influence in the calculations ($V_{k+1,1}=V_{k,0}$, $L_{k+1,1}=L_{k+1,0}$). The feed Gf_k is aligned with difference points (DP) Δ_k and Δ_{k+1} and this line crosses the dew curve in a unique point FP used as the reference for the calculation. Nevertheless, some authors consider the change of sector DP Δ_k^C when the side stream is a partly vaporized feed [3]. To complete the academic literature dealing with this subject we have generalized equations for the operating lines or DP that define the change between two consecutive sectors Δ_k^C for any feed condition, together with the different possibilities to extract products or to add or remove heat. According to nomenclature of Figure 2:

$$V_{k+1,i+1}\cdot y_{k+1,i+1}-L_{k+1,i}\cdot x_{k+1,i}=D\cdot x_D-\sum_{S=1}^{k}MF_S\cdot z_{GFS}=\Delta_{k+1}z_{k+1}\qquad z_{k+1}=\left(D\cdot x_D-\sum_{S=1}^{k}MF_S\cdot z_{GFS}\right)\Big/\Delta_{k+1}\qquad M_k^C=(\Delta_k M_k-V_{GFk}H_{GFk})/\Delta_k^C=(L_{GFk}h_{GFk}+\Delta_{k+1}M_{k+1})/\Delta_k^C$$

$$V_{k+1,i+1}\cdot H_{k+1,i+1}-L_{k+1,i}\cdot h_{k+1,i}=D\cdot h_D+Q_D-\sum_{S=1}^{k}EF_S=\Delta_{k+1}M_{k+1}\qquad \Delta_k^C=\Delta_k-V_{GFk}\qquad \Delta_k^C=L_{GFk}+\Delta_{k+1}\qquad z_k^C=(\Delta_k z_k-V_{GFk}y_{GFk})/\Delta_k^C=(L_{GFk}x_{GFk}+\Delta_{k+1}z_{k+1})/\Delta_k^C$$

In this work all the streams involved in the connecting sector zones, as well as the corresponding DP, and their characteristics IP_k and IP_{k+1}, which define the optimum position for the side stream, are located in the diagrams. The example in Fig. 1b shows the case where the vapour and liquid portions of the feed stream differ with the streams developed in the column: V_{GFk} joins the vapour coming from the stage below ($V_{k,0}=V_{k+1,1}+V_{GFk}$), which implies that $V_{k,0}$ is aligned between $V_{k+1,1}$ and V_{GFk}; whereas L_{GFk} joins the liquid coming from the plate immediately above ($L_{k+1,0}=L_{k,NTk}+L_{GFk}$) so $L_{k+1,0}$ is aligned between $L_{k,NTk}$ and L_{GFk}. In this case, neither $V_{k,0}$ nor $L_{k+1,0}$ are in equilibrium, so they are located outside the H,h/x curves, as shown in the magnifications presented in Fig.1b specified ones, since relationships among streams occurring in the changing sector zone are not fulfilled

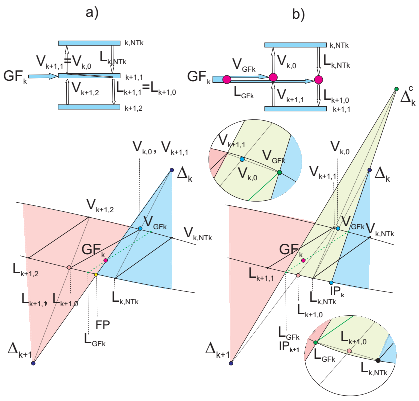

Figure 1. Ponchon-Savarit H,h-y,x diagram and streams at the side stream stage for a generalized feed: a) FP approach; b) considering the sector of change.

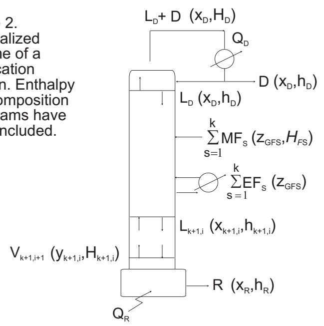

Figure 2. Generalized scheme of a rectification column. Enthalpy and composition of streams have been included.

Systematic analysis of the changes of sector

A systematic analysis of the different possible situations is presented in Figure 3. This analysis does not only show the relationships occurring among the ZCCS but also between them and the rest of streams at the previous or subsequent stages.The streams developed in the rectification column can coincide with one of the vapour (V_{GFk}) or liquid (L_{GFk}) portions generated from the generalized feed and then be coincident with one of both streams defining the ZCCS (i.e. $V_{k+1,1}$ or $L_{k,NTk}$), as shown in column 2 and 3 of the figure. Otherwise, the equilibrium streams developed can differ from those originated from the side stream and lie inside the ZCCS, which should only be used once during the tray calculations (column 4).

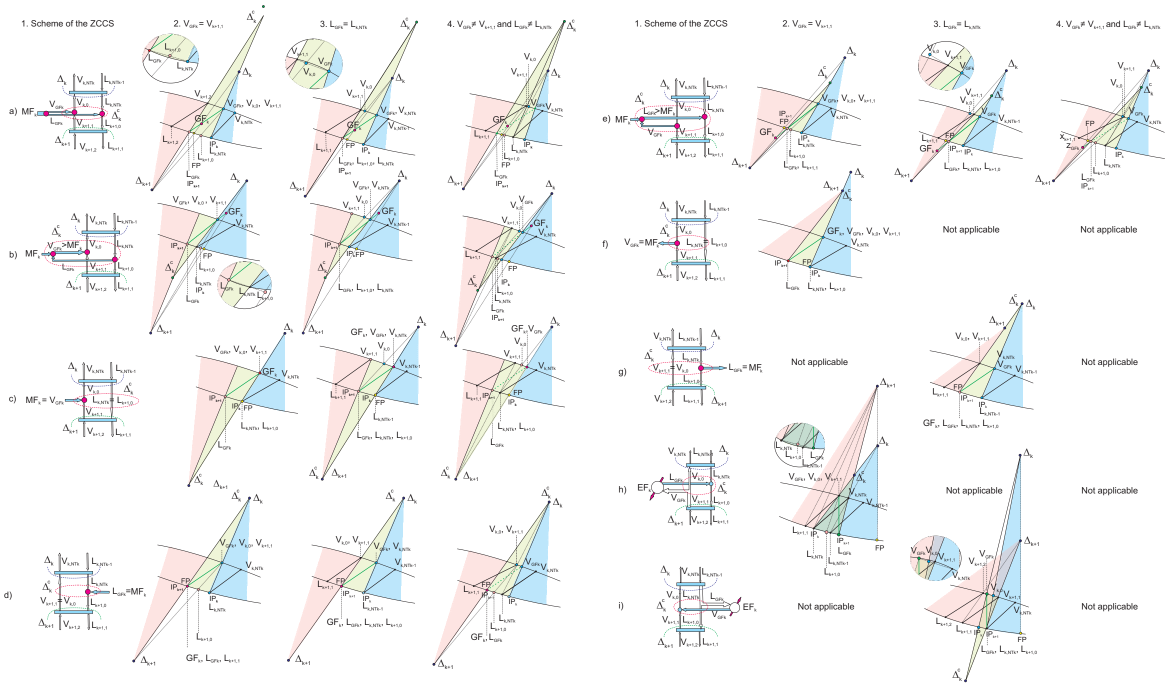

Figure 3. . Ponchon-Savarit y-x diagrams for a GF_k: a) $MF_k>0$, $0<q_{GFk}<1$; b) $MF_k>0$, $q_{GFk}<0$; c) $MF_k>0$, $q_{GFk}=0$; d) $MF_k>0$, $q_{GFk}=1$; e) $MF_k>0$, $q_{GFk}>1$; f) $MF_k<0$, $q_{GFk}=0$; g) $MF_k<0$, $q_{GFk}=1$; h) $EF_k<0$; i) $EF_k>0$. For each one of these GF_k, different cases are analysed: 1. Scheme of the ZCCS; 2. $V_{GFk}=V_{k+1,1}$; 3. $L_{GFk}=L_{k,NTk}$; 4. $V_{GFk}?V_{k+1,1}$ and $L_{GFk}?L_{k,NTk}$.

This detailed analysis shows that, when solving a case of a design calculation products can only be extracted from liquid or vapour streams that actually exist in the column, and heat extractions or additions can also be done to existing streams, if not the specifications of the column must be updated. Any other consideration leads to incoherent design predictions since relationships among streams occurring in the ZCCS are not fulfilled.

From the study of different examples we can state that the result obtained by using the *strict* ZCCS Ponchon-Savarit method and the FP approach may be nearly the same, though depending on the equilibrium of the particular system analysed and other variables. However the presented procedure provides a clear analysis of what is happening at the column, and allows being aware of the type of approximation normally carried out, thus facilitating the comprehension of the method, that otherwise could be misunderstood or difficult to be explained.

References

[1] McCabe, W.L, Thiele, W.E. Ind. Eng. Chem. 1925, 17, 605.
[2] Ponchon, M. Tech. Modern, 1921, 13, 20. Savarit, R. Arts et Métiers, 1922, 3, 65.
[3] Ledanois, J.M.; Olivera-Fuentes, C. Ind. Eng. Chem. Process Des. Dev. 1984, 23, 1-6.
[4] Marcilla, A.; Serrano, M.D.; Reyes-Labarta, J.A. Ind. Eng. Chem. Res. 2011. (Under review)