GRAPHICAL REPRESENTATION OF THE CHANGES OF SECTOR FOR PARTICULAR CASES IN THE PONCHON SAVARIT METHOD

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Abstract

A graphical and systematic analysis of particular cases where the compositions of the streams developed in the rectification column coincide with one of the vapor (y_{GFk}) or liquid (x_{GFk}) portions generated from the G_{Fk} can be found in this material (i.e.: $y_{GFk}=y_{k+1,1}$ or $x_{GFk}=x_{k,NTk}$).

Keywords: **Distillation; Side Stream; Process Design; Heat Stages; Lateral Product.**

In this work, we will analyze the general situation of a mass feed stream ($M_{GFk}>0$) for different thermal conditions of the feed stream (q_{GFk}), but in specific cases where the compositions of the vapor (y_{GFk}) or the liquid (x_{GFk}) portion generated from the GF_k is coincident with one of both streams defining the stage of the change of sector (i.e. $y_{k+1,1}$ or $x_{k,NTk}$). Though these situations only happen by improbable coincidences, they can be interesting to be analyzed due to the relationships occurring among the streams developed in the column.

A. Mixture of a liquid and vapor in equilibrium ($0 \leq q_{GFk} \leq 1$)

In case the thermal condition of the feed allows the composition of that liquid stream ($x_{k,NTk}$) coincide with the x composition corresponding to IP_k, or the composition of the first vapor stream ascending from the next sector coincide with the y composition corresponding to IP_{k+1}, the composition of the feed stream vapor and liquid portions match exactly with that of one of the streams present in the column.

If the x composition of IP_k coincides with that of the liquid falling from the last stage above the feed $x_{k,NTk}$, then all composition of vapour streams in the change of sector match: $y_{GFk}=y_{k,0}=y_{k+1,1}$. The stream $L_{k+1,0}$ of composition $x_{k+1,0}$ is in the straight line joining Δ_{k+1} with $V_{k+1,1}$ of composition $y_{k+1,1}=y_{GFk}$ (Figure 1.a) though not located on the bubble-point curve h=f(x) but in the straight line joining L_{GFk} and $L_{k,NTk}$, since it is the summation of such equilibrium streams (see the magnification if the corresponding figure). Only if the h=f(x) was a straight line (i.e. in the McCabe-Thiele method) $L_{k+1,0}$ could be considered an equilibrium stream.
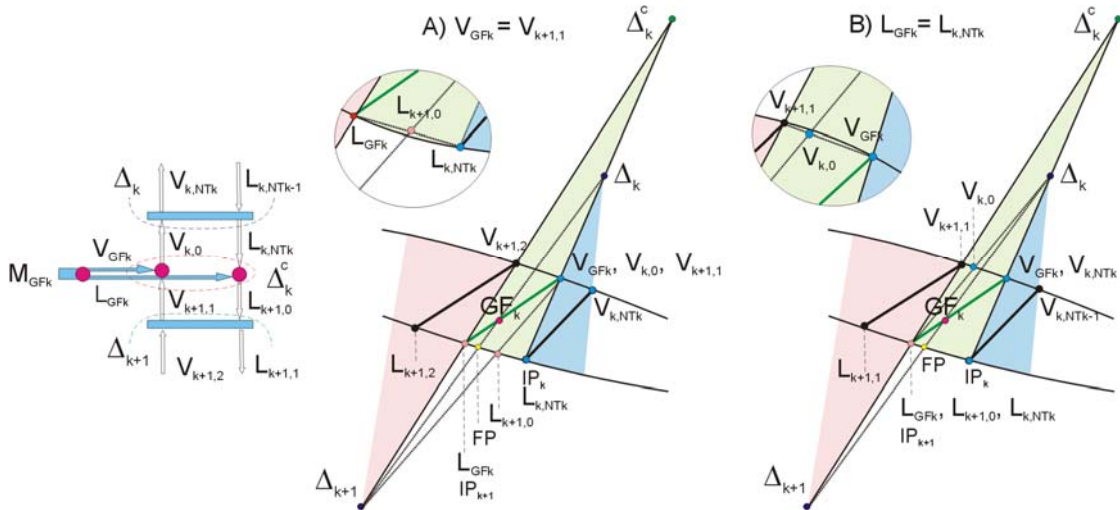
Figure 1. *Ponchon-Savarit diagrams for a feed stream ($M_{GFk}>0$) and $0<q_{GFk}<1$: a) $y_{GFk}=y_{k+1,1}$; b) $x_{GFk}=x_{k,NTk}$*

If the x composition (Figure 1.b) of IP_{k+1} was that coinciding with the liquid descending from the last tray of the sector above $L_{k,NTk}$ (of composition $x_{k,NTk}$), the three liquids would have the same composition $x_{GFk}=x_{k,NTk}=x_{k+1,0}$ and $V_{k,0}$ would be in the intercept of the line joining Δ_k with $L_{k,NTk}$ (of composition $x_{k,NTk} = x_{GFk}$), with the line joining V_{GFk} and $V_{k+1,1}$. In this case $V_{k,0}$ is not located on the vapour curve since it is not an equilibrium stream. The construction is obviously equivalent to that one shown in Figure 1.a since the two situations represent both ends of the same tie-line.

In these two cases the effect of the feed stream causes the vapour and liquid portions to match exactly with one of the equilibrium streams present: $y_{GFk}=y_{k+1,1}$ and $x_{GFk}=x_{k,NPk}$, respectively.

B. Superheated vapor ($q_{GFk}<0$)

Again, depending on the composition of the vapor feed, two situations can occur that allow y_{GFk} or x_{GFk} match exactly with one of the streams present in the column.

According to Figure 2.a, if the composition of the feed vapour fraction coincides with the composition of the vapour ascending from the first stage of the subsequent sector ($y_{GFk}= y_{k+1,1}$), all vapour stream compositions generated in the change of sector are the same: $y_{k+1,1}= y_{k,0}$. It can be observed that in the case of this superheated vapour feed, $L_{k+1,0}$ ($x_{k+1,0}$) is aligned but not in between $L_{k,NTk}$ ($x_{k,NTk}$) and L_{GFk} (x_{GFk}) since $x_{k+1,0}$ is greater than $x_{k,NTk}$ because L_{GFk} is negative and this addition (that is actually a substraction) has an unfavourable effect on the separation at the stage of the sector change.

On the other hand, if we accept that the composition of the liquid streams developed in the change of sector streams coincides (Figure 2.b), and then the feed liquid fraction has the same composition as the liquid falling from the last tray of the previous sector and the liquid arriving to the first tray of the next sector ($x_{GFk} = x_{k,NTk} = x_{k+1,0}$), then it must be accepted that the feed vapour composition fraction matches up with the vapour ascending from the last stage of sector k: $y_{GFk} = y_{k,NTk}$. The V_{GFk} joins the vapour coming from the stage below: $V_{k,0} = V_{k+1,1} + V_{GFk}$ and

the diagram shows that $y_{k,0}$ is aligned between $y_{k+1,1}$ and y_{GFk} (analogously to the case shown in the magnification in Figure 1.b), since the streams being added are both positive.
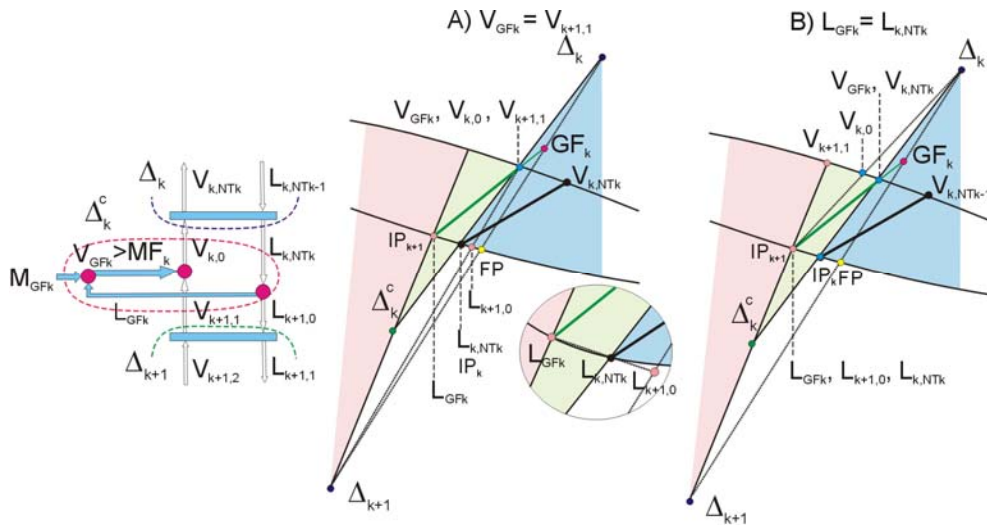

Figure 2. *Ponchon-Savarit diagrams for a superheated vapor feed stream ($M_{GFk}>0$ and $q_{GFk}<0$): a) $y_{GFk}=y_{k+1,1}$; b) $x_{GFk}=x_{k,NTk}$*

C. Saturated vapor ($q_{GFk}=0$)

If the composition of the feed vapour fraction V_{GFk} coincides with the composition of the vapour ascending from the first stage of the subsequent sector, as shown in the case represented in Figure 3.a, then the compositions of all vapour streams at the ZCCS are the same ($y_{GFk}= y_{k+1,1}= y_{k,0}$). In the case where the composition of the liquid L_{GFk}, in equilibrium with V_{GFk}, together with the composition of the liquid streams generated ($L_{k,NTk}$, $L_{k+1,0}$), are coincident: $x_{k,NTk}= x_{GFk}= x_{k+1,0}$, (Figure 3.b) then it must be accepted that the composition of V_{GFk} matches up with that of the last stage of the previous sector $V_{k,NTk}$ ($y_{GFk}=y_{k,NTk}$), as occurred for the superheated vapour feed (illustrated in Figure 2.b). It can be observed that $V_{k,0}$ ($y_{k,0}$) is aligned between $V_{k+1,1}$ ($y_{k+1,1}$) and V_{GFk} (y_{GFk}). Both cases, presented in Figures S3.a,b lead, obviously, to the same number of steps.
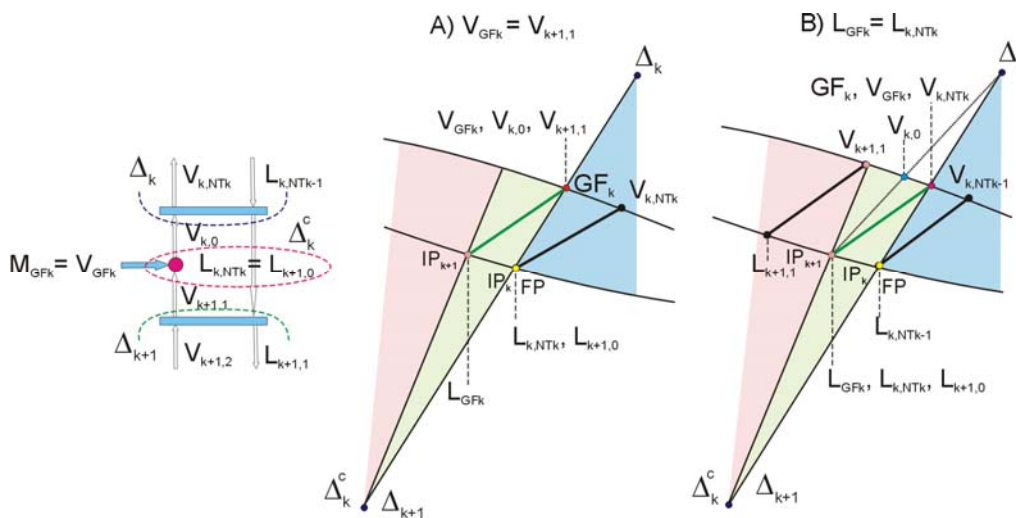

Figure 3. *Ponchon-Savarit diagrams for a saturated vapor feed stream ($M_{GFk}>0$ and $q_{GFk}=0$): a) $y_{GFk}=y_{k+1,1}$; b) $x_{GFk}=x_{k,NTk}$*

D. Saturated liquid (q_{GFk} =1)

The composition of vapour streams $V_{k,0}$ and $V_{k+1,1}$ are the same: $y_{k,0}=y_{k+1,1}$. If they also match up with the composition of the vapour in equilibrium with the feed V_{GFk} ($y_{GFk} = y_{k,0} = y_{k+1,1}$), as shown in Figure 4.a, then it must be accepted that compositions of L_{GFk} and $L_{k+1,1}$ are the same ($x_{GFk} = x_{k+1,1}$), and the relationship between the liquid streams ($x_{k+1,0} = x_{GFk} + x_{k,NTk}$) is fulfilled analogously to the case shown in the magnification in Figure 4a2. For the case represented in Figure 4.b, compositions of L_{GFk} and $L_{k,NTk}$ are the same ($x_{GFk}=x_{k,NTk}$) and composition of $V_{k,0}$ and $V_{k+1,1}$ coincide ($y_{k,0}=y_{k+1,1}$), analogously to Figure 4.a, despite the y_{GFk} being different.

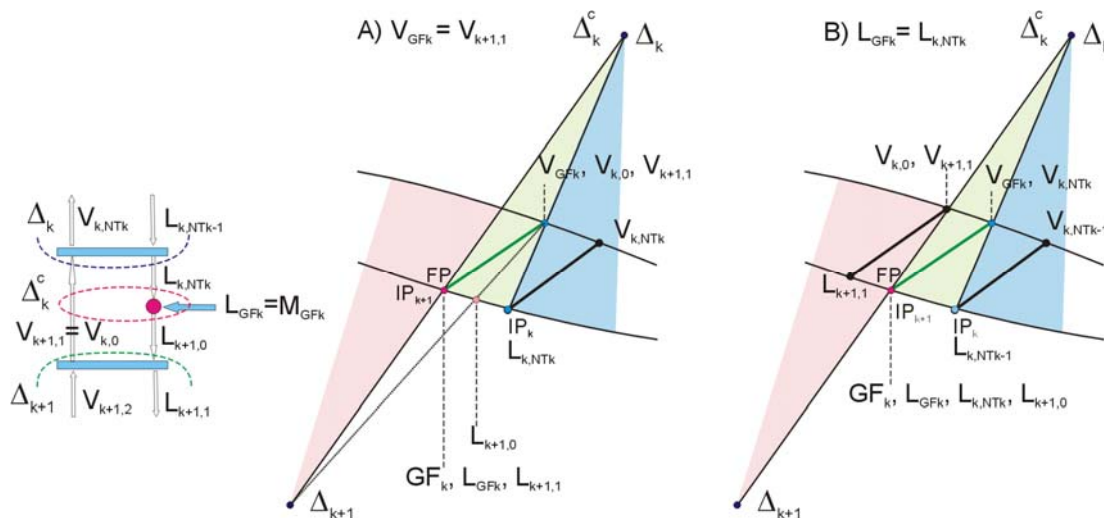**Figure 4.** *Ponchon-Savarit diagrams for a saturated liquid feed stream ($M_{GFk}>0$ and $q_{GFk}=1$): a) $y_{GFk}=y_{k+1,1}$; b) $x_{GFk}=x_{k,NTk}$*

E. Undercooled liquid (q_{GFk} >1)

According to Figure 5.a, if we accept that the composition of the vapour streams in the change of sector does not vary ($y_{k,0}= y_{GFk}= y_{k+1,1}$), then the feed liquid composition x_{GFk} must coincide with composition of $L_{k+1,1}$ ($x_{k+1,1}$). The L_{GFk}, joins the liquid coming from the stage above: $L_{k+1,0} = L_{k,NTk} + L_{GFk}$, so $x_{k+1,0}$ is aligned between $x_{k,NTk}$ and x_{GFk} as occurred in the magnification of Figure 1.a.

If the composition of L_{GFk} is coincident with the composition of the liquid $L_{k,NTk}$ descending from the last stage of sector k ($x_{GFk}= x_{k,NTk}= x_{k+1,0}$), all three liquids L_{GFk}, $L_{k,NTk}$ and $L_{k+1,0}$ are coincident with IP_{k+1} (Figure 4e3). In this case Vk,0 (yk,0) is aligned with $V_{k+1,1}$ ($y_{k+1,1}$) and V_{GFk} (y_{GFk}) but not in between ($y_{k+1,1}>y_{k,0}$ as shown in the magnification of Figure 5.b) because V_{GFk} is negative and the undercooled liquid stream addition produces an unfavourable situation for the separation.
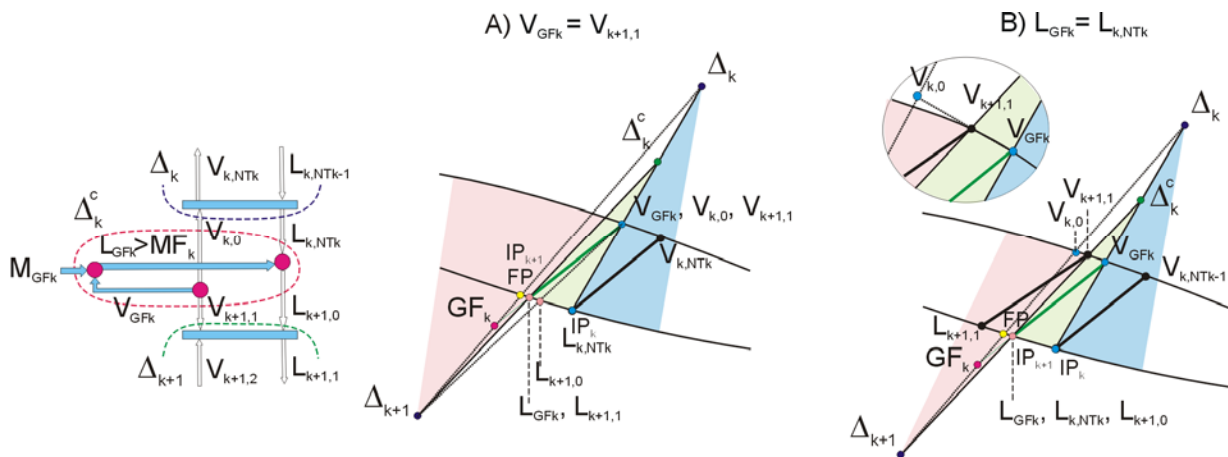
Figure 5. *Ponchon-Savarit diagrams for a undercooled liquid feed stream ($M_{GFk}>0$ and $q_{GFk}>1$): a) $y_{GFk}=y_{k+1,1}$; b) $x_{GFk}=x_{k,NTk}$*

REMARK

A resume of the Extension of the Ponchon and Savarit Method for Designing Ternary Rectification Columns can also be found in the Open Academic Repository of the University of Alicante (http://hdl.handle.net/10045/14600; /14601, and /10023). Additionally, a website of self-learning about the Ponchon-Savarit method for the design of distillation columns can be consulted: http://iq.ua.es/Ponchon/.

In an equivalent way, a review and extension of the McCabe Thiele method and the completed deduction of the generalized equations can also be found in the Open Academic Repository of the University of Alicante (http://hdl.handle.net/10045/23195), and a website of self-learning about the McCabe-Thiele method for the design of distillation columns can be consulted: http://iq.ua.es/McCabe-V2/ (http://hdl.handle.net/10045/2283).

LIST OF SYMBOLS

C_{PL}, C_{PV} Specific heats of liquid and vapor phase

E_{GFk} Effective heat flow (kcal/h) added or removed to the column, after section k, by an intermediate heat exchanger (reboiler or condenser that we consider having a 100% efficiency) to a liquid or a vapor stream, respectively

GF_k Generalized feed that separates section k and k+1 (kmole/h)

H_{GFk} Specific enthalpy of the generalized feed mixture stream (kcal/kmole)

H_{GFk} Dew-point vapor enthalpy (kcal/kmole)

h_{GFk} Bubble point liquid enthalpy (kcal/kmole)

L_{GFk} Liquid portion of the generalized feed stream k

$L_{k,i}$ Liquid from stage i of section k (kmole/h)

λ_{GFk} Enthalpy of vaporization or latent heat (kcal/kmole) of the feed stream

M_{GFk} Mass feed or product stream that separates section k and k+1 (kmole/h)

q_{GFk} Thermal condition of the generalized feed stream k. Enthalpy change to bring the mass feed stream from its initial condition (H_{GFk}) to a saturated vapor (H_{GFk}) divided by the molar latent heat or enthalpy of vaporization of the feed λ_{GFk} (dew-point vapor enthalpy, H_{GFk}, minus bubble point liquid enthalpy, h_{GFk})

$$q_{GFk} = \frac{H_{GFk} - H_{GFk}}{H_{GFk} - h_{GFk}} = \frac{H_{GFk} - H_{GFk}}{\lambda_{GFk}}$$

$$q_{GFk(undercooled\ liquid)} = \frac{H_{GFk} - [\,h_{GFk} + C_{PL} \cdot (T_{GFk} - T_{boiling\ point}\,)]}{\lambda_{GFk}} = 1 + \frac{C_{PL} \cdot (T_{boiling\ point} - T_{GFk})}{\lambda_{GFk}} > 1$$

$$q_{GFK(superheated\ vapor)} = \frac{H_{GFK} - [\,H_{GFK} + C_{PV} \cdot (T_{GFK} - T_{dew\ point}\,)]}{\lambda_{GFK}} = \frac{-C_{PV} \cdot (T_{GFK} - T_{dew\ point})}{\lambda_{GFK}} < 0$$

T_{GFk} Temperature of the generalized feed stream k

V_{GFk} Vapor portion of the generalized feed stream k

$V_{k,i}$ Vapor from stage i of section k (kmole/h)

x_{GFk} Liquid feed composition of the volatile component (mole fraction)

x_{IPk} x coordinate of the point IP_k ($=x_{opt,k}$)

x_{IPk+1} x coordinate of the point IP_{k+1} ($=x_{GFk}$)

$x_{k,i}$ Composition of liquid falling from stage i of section k (mole fraction)

y_{GFk} Vapor feed composition of the volatile component (mole fraction)

$y_{k,i}$ Composition of vapor ascending from stage i of section k (mole fraction)

y_{IPk} y coordinate of the point IP_k ($=y_{GFk}$)

z_{GFk} Generalized feed composition of the volatile component (mole fraction)

Subscripts

i   Stage

k   Section

NTk   Number of plates of the section k

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