ANALYSIS OF THE CONNECTING ZONE BETWEEN CONSECUTIVE SECTIONS IN DISTILLATION COLUMNS COVERING MULTIPLE FEEDS, PRODUCTS AND HEAT TRANSFER STAGES

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Abstract— In the present work, we provide a systematic analysis about all the streams involved in the zone connecting two consecutive sections for the design of distillation columns with different thermal feed conditions, product extractions and heat additions or withdrawals. This analysis allows a better understanding of what happens on a feed or side draw (of mass or energy) stage, what compositions are or are not in equilibrium, and the impact on internal liquid and vapor flows.

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

I. INTRODUCTION

Tray by tray methods for the design of distillation columns cannot compete with computer methods, but they are essential for their conceptual design. These methods do provide a clear picture of what could be expected in an approximate way along a distillation column and facilitates the visualization and best understanding of many fundamentals and important aspects of multistage distillation, such as the interrelationship of several process variables.

In this sense, typical practical calculations for the conceptual design of a distillation column, given for instance a known recovery of the key components, can be: optimal number of trays or reflux ratio, minimum number of trays (at total reflux), detecting pinched zones (minimum reflux), excessive reflux or reboil and mislocated feed streams, identifying cases where intermediate heat exchangers are attractive, etc. Therefore most mass transfer text books in chemical engineering devote some space and effort to explain tray by tray methods, such as the McCabe-Thiele method (Seader et al., 2011; Petlyuk, 2004; Stichlmair and Fair, 1998; Biegler et al., 1997; Kister, 1992; King, 1980; Treybal, 1981; Henley and Seader, 1988; Benitez, 2002; Noble and Terry, 2004). However, equations for the operating lines (OL) are always developed for columns with single or multiple feed additions but product extractions and heat additions or withdrawals are not always considered.

Furthermore, the optimum point of feed introduction, which yields the least total number of trays at a particular reflux, is generally consider as the intersection point between the operative lines of the sector above and below (FP point), in order to use always at each step, the operative line that lies farther from the equilibrium curve to obtain the maximum enrichment per stage (i.e. lowest vapor composition if we start at the top of the column). Therefore, when a mass feed stream is considered, whatever its thermal condition, such optimum feed location consideration is consequent with the assumption that the feed is introduced in bulk to a single feeding tray (stage number 2 in Fig. 1a) where it mixes with the vapor of the tray below and with the liquid of the tray above. The streams leaving this feeding stage (V_2=L_2 and L_2=L_1') are considered to be in equilibrium, as in any other theoretical stage (Fig. 1a).

However, this approach can be somewhat far from the physical reality, that does not allow to exactly locate all the streams involved in the changing zone of two consecutive sectors in the McCabe-Thiele diagram, and that can introduce some significant deviations in the equilibrium compositions obtained for the different trays of the column below each particular feed, especially in systems of high relative volatility and when the feed is a subcooled liquid, a partly vaporized mixture or a superheated vapor. Thus, it is more likely to consider that when a feed stream is introduced in the distillation column, it flashes adiabatically and spontaneously to the feed stage pressure, generating a vapor phase (V_F) that flows to the tray immediately above, and a liquid phase (L_F) that flows to the tray immediately below (Fig. 1b).

Before dealing with the general case, the differences of the classical and strict approach in the case of a single feed stream are shown in Fig. 2a-b (corresponding to the schemes presented in Fig. 1a-b), with a simplified nomenclature. With the classical approach, when the step by step construction arrives to the composition y_3=y_2' by using the upper section operative line (UOL), the liquid composition x_3 is obtained directly from the equilibrium curve. The composition of the next vapor y_3 is located in the OL of the following sector, LOL. As we can see, stream L_2=L_1+L_F presents an inconsistent behavior in the sense that its composition (x_2) is located out side the interval defined by the compositions x_1 and x_F (Fig. 2a).

In an alternative approach, what is supposed to occur is that when a feed stream is introduced between two plates in the distillation column (1 and 2 in Fig. 1b), it flashes adiabatically. The vapor fraction V_F will join the vapor coming from the stage below V_2, whereas the feed liquid fraction L_F will join the liquid coming from the plate immediately above L_1, providing two streams (V_2' and L_1') that are not in equilibrium: V_2'=V_2+V_F=V_2+F-L_F and L_1'=L_1+L_F, since they are the sum of two different streams that are in equilibrium. Figure 1b presents the feed operative line (FOL) and all the streams...