How Hydraulics Affects Efficiency in Towers — Part 1: Trays

There are many different definitions of mass transfer efficiency but they are all intended to allow the number of theoretical stages (NTS) or the number of theoretical plates (NTP) to be translated into the number of real trays (N), or the actual height of packing (H), needed to achieve a certain separation. The simplest is the overall efficiency (\( \eta \)) for trays, HETP for packing) which allows for a direct translation between theoretical and actual:

\[ \eta = \frac{NTS}{N}; \quad HETP = \frac{H}{NTS} \]

For binary systems, NTS can be calculated graphically either using a McCabe-Thiele x-y diagram or, for systems with large heat effects, using the Ponchon-Savarit (H-x-y) graphical method. For multicomponent systems the concept of key components is most often used. These methods, ingenious at the time, were developed to allow distillation calculations to be done graphically, long before the advent of digital computers. Today, NTS is calculated digitally with great speed while avoiding simplifying assumptions such as equimolar overflow. The central problem with using theoretical stages, however, is determining the efficiency or HETP, especially for a new system, or for a familiar system under unfamiliar operating conditions. Efficiencies are hard to calculate reliably (see Duss and Taylor\(^\ddagger\)) for very readable expositions). Perhaps in part the difficulty stems from our inability to quantify accurately the extent of back-mixing of liquid as it crosses a tray and back-mixing of liquid as it descends through a bed of packing, something that is related directly to hydraulics.

**Tray and Packing Hydraulics**

Vapour flow through trays and packed beds is predominantly in the vertical direction and, unless there is significant vapour maldistribution, there is limited opportunity for vapour back-mixing. The same cannot be said for liquid flows. At first glance, the liquid flows, in trayed versus packed columns appear quite different; however, the difference is somewhat superficial. Liquid flows horizontally across a tray where it contacts the vapour before descending through downcomers. There is no axial dispersion during the flow from tray to tray (unless there is entrainment or weeping) but there is a variety of patterns possible as the liquid flows across the tray. As shown in Figure 1, these range from plug flow to completely mixed, with varying recirculation patterns between the extremes. The state of liquid mixing affects the tray’s efficiency. For example, with liquid traversing the tray in nearly plug flow it is quite possible to realize an overall tray efficiency well in excess of 100%. This is not possible if the liquid is completely mixed or shows recirculation as in Figure 1(a).


\(^\ddagger\) Duss, M.; Taylor, R.; Predict Distillation Tray Efficiency, www.aiche.org/cep, July, 2018
The truth is somewhere between these limits. ProTreat® segments packed towers according to general rules of thumb and internally chosen generalised heuristics to achieve best agreement with a library of performance data. There is rough equivalence between a packed segment and a real tray but these devices have very different mass transfer characteristics because of different modes of phase contact, so they perform quite differently.