Multicomponent Vapor - Liquid Cascades

Keywords: Vapor Liquid Equilibria, Vapor Liquid Cascades, Group Methods, Absorption & Strapping factor methods.

Counter current cascades are used extensively for vapor –liquid separation operations such as absorption, stripping and distillation. For absorption and stripping a single-section cascade is used to recover designated components from the feed. For distillation a two section cascade is effective in achieving a separation between two selected components referred to as key component. The approximate method which is used in single section cascade is known as group method. Kremser originated the group method by deriving an equation fractional absorption of a species from a gas into a liquid absorbent for multistage countercurrent absorber.

Consider the counter current cascade of N adiabatic equilibrium stages used as shown in figure, to absorb species present in the entering vapor. Assume these species are absent in the entering liquid. Stages are numbered from top to bottom. It is convenient to express stream composition in terms of component molar flow rates υ_i and l_i , in the vapor and liquid phases, respectively. In the following derivation, the subscript is dropped. A material balance around the top of the absorber, including stages 1 through N-1 for any absorbed species gives the following equations:

$L_o x_o + VNyN = L_{N-1} x_{N-1} + V_1 y_1$

Or $1_0 + UN = 1_{N-1} + U1$

Where $U = V_y and 1 = L_x$

but $1_0 = 0 \sin cex_0 = 0;$

Hence $UN = U_1 + U_{N-1}$ …31.1

From equilibrium consideration for stage N, the definition of the vapor- liquid equilibrium ration on K value can be used to give

$YN = K_N X_N$ …31.2

Or $V_{NyN} = (K_N V_N L_{Nx}) / L_N$

$OruN = (K_N V_N 1_N X) / L_N$

Or $UN = (1_N x) / (L_N / K_N - V_N)$ …31.3

Now we define an absorption factor, A

A=L/ (KV) …31.4

Hence $UN = 1_N / A_N$ …31.5

Substituting equation (5) into equation (1)

$1_N / A_N = U1 + 1_{N-1}$

$or\, 1_N = (U1 + 1_{N-1}) A_N$ …31.6

The internal flow rate, l_{N-1}, is eliminated by successive substitution using material balances around successively smaller sections of the top of the cascade. For stages 1 through N-2,

$1_{N-1} = (U1 + 1_{N-2}) A_{N-1}$ …31.7

Substituting eq (7) into equation (6)

$1_N = ((U1 + 1_{N-2}) A_{N-1} + U1) A_N$

$Or 1_N = 1_{N-2}. A_{N-1} A_{N+} U1 (A_N + A_{N-1} A_N)$ …31.8

Continuing this process to the top stages (N-3, N-4 …3, 2, 1)

$1_{N-2} = (U_1 + 1_{N-3}) A_{N-2}$

$1N = (((U1 + 1_{N-3}) A_{N-2}) A_{N-1} + U1) A_N$

$1N = (U1 + 1_{N-3}) A_{N-2} A_{N-1} (A_N + A_{N-2} A_{N-1} A_N)$

$1N = (U1 + 1_1) A_1 A_2 A_3 ... A_N + U1 (A_N + A_1 A_2 A_3 .. A_N)$

$1_1 = U_1 A_1$

$1_N = U1(A_1 A_2 A_3 ... A_N + A_3 .. A_N + ... AN)$ …31.9

Overall component balance

$1_0 + UN + 1 = 1_N + U_1$

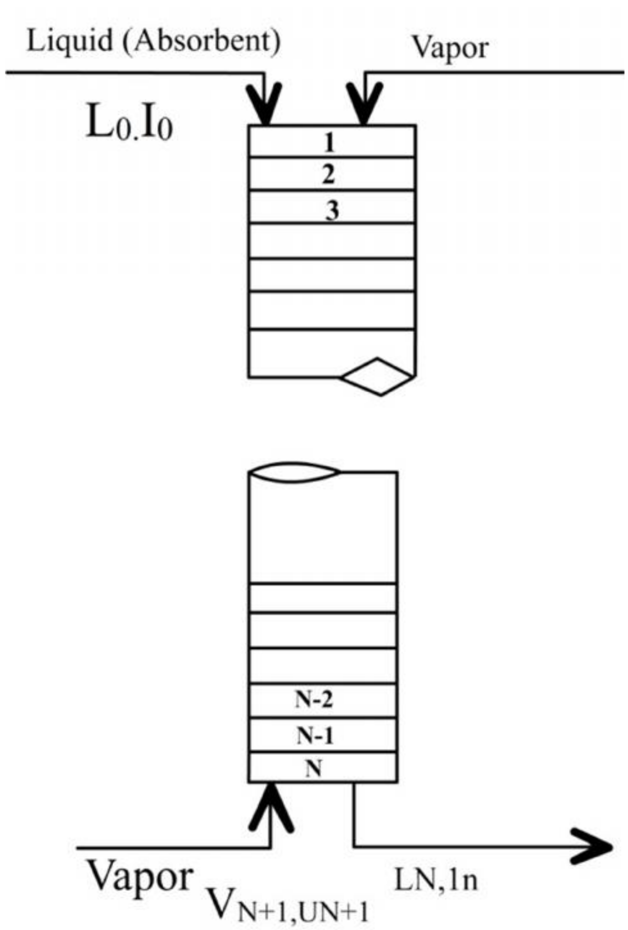

Fig. 31.1: Vapor liquid counter current Absorber column

$1_N = U_{N+1} - U1$ …31.10

Or $UN + 1 - U1 = U1(A_1 A_2 A_3 .. A_N + A_2 A_3 ... A_N + .. + A_N)$

Or $UN + 1 = U1(A_1 A_2 A_3 ... A_N + A_2 A_3 ... A_N + A_3 .. A_N + ... + A_N + 1)$

Or $U1 = UN + 1¤ A$ …31.11

Where ϕA is the recovery fraction which is defined as

$$\phi A = 1/(A_1 A_2 A_3 ... A_N + A_3 .. A_N + ... + A_N + 1) \qquad ...31.12$$

= fraction of species in entering vapor that is not absorbed.

In the group method, an average effective absorption factor, A_e, replaces the separate absorption factor for each stage.

$$\phi A = 1/(A_e^N + A_e^{N-1} + A_e^{N-2} + ... + A_e + 1) \qquad ...31.13$$

Multiplied and divided by (A_e-1) in equation (…31.13)

$$\phi A = (A_e - 1)/(A_e^N + A_e^{N-1} + A_e^{N-2} + ... + A_e + 1)(A_e - 1)) \qquad ...31.14$$

$$\phi A = (A_e - 1)/(A_e^{N+1} - 1)$$

Note that each component has different A_e and therefore different value of ϕ_A .

Figure is a plot with a probability scale for ϕ_A and a logarithmic scale for A_e and N as a parameter. This plot in linear coordinates was first developed by Kremser.

If we consider the counter current stripper then

$$1_1 = 1_{N+1} + \phi_S \qquad ...31.15$$

Fraction of species in entering liquid that is not stripped

$S = K.V / L = 1/A =$ = stripping factor.

Insert from Book 168 fig. 169 example 5.3 170 before two sections pera