below the feed plate, and hence an increased heat consumption from the boiler per mole of distillate.

11.4.3. The importance of the reflux ratio

Influence on the number of plates required

The ratio L_n/D, that is the ratio of the top overflow to the quantity of product, is denoted by R, and this enables the equation of the operating line to be expressed in another way, which is often more convenient. Thus, introducing R in equation 11.35 gives:

$$y_n = \left(\frac{L_n}{L_n + D}\right) x_{n+1} + \left(\frac{D}{L_n + D}\right) x_d \tag{11.47}$$

$$= \left(\frac{R}{R+1}\right) x_{n+1} + \left(\frac{x_d}{R+1}\right) \tag{11.48}$$

Any change in the reflux ratio R will therefore modify the slope of the operating line and, as may be seen from Figure 11.15, this will alter the number of plates required for a given separation. If R is known, the top line is most easily drawn by joining point A (x_d, x_d) to B $(0, x_d/(R+1))$ as shown in Figure 11.17. This method avoids the calculation of the actual flow rates L_n and V_n, when the number of plates only is to be estimated.

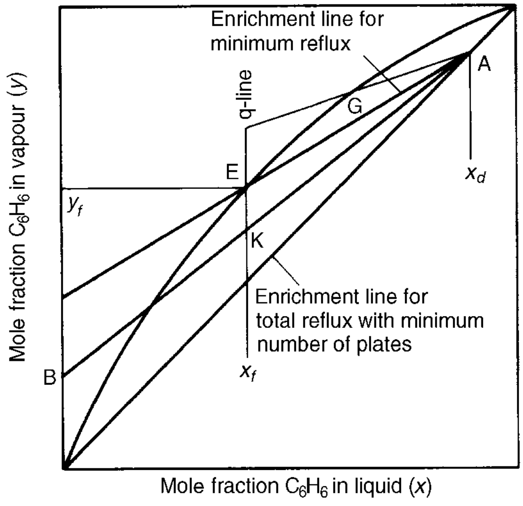

Figure 11.17. Influence of reflux ratio on the number of plates required for a given separation

If no product is withdrawn from the still, that is $D = 0$, then the column is said to operate under conditions of total reflux and, as seen from equation 11.47, the top operating line has its maximum slope of unity, and coincides with the line $x = y$. If the reflux ratio is reduced, the slope of the operating line is reduced and more stages are required to pass from x_f to x_d, as shown by the line AK in Figure 11.17. Further reduction in R will eventually bring the operating line to AE, where an infinite number of stages is needed to pass from x_d to x_f. This arises from the fact that under these conditions the steps become very close together at liquid compositions near to x_f, and no enrichment occurs from the feed plate to the plate above. These conditions are known as *minimum reflux*, and the reflux ratio is denoted by R_m. Any small increase in R beyond R_m will give a workable system, although a large number of plates will be required. It is important to note that any line such as AG, which is equivalent to a smaller value of R than R_m, represents an impossible condition, since it is impossible to pass beyond point G towards x_f. Two important deductions may be made. Firstly that the minimum number of plates is required for a given separation at conditions of total reflux, and secondly that there is a minimum reflux ratio below which it is impossible to obtain the desired enrichment, however many plates are used.

Calculation of the minimum reflux ratio

Figure 11.17 represents conditions where the q-line is vertical, and the point E lies on the equilibrium curve and has co-ordinates (x_f, y_f). The slope of the line AE is then given by:

$$\left(\frac{R_m}{R_m + 1}\right) = \left(\frac{x_d - y_f}{x_d - x_f}\right)$$

or:

$$R_m = \left(\frac{x_d - y_f}{y_f - x_f}\right) \tag{11.49}$$

If the q-line is horizontal as shown in Figure 11.18, the enrichment line for minimum reflux is given by AC, where C has coordinates (x_c, y_c). Thus:

$$\left(\frac{R_m}{R_m + 1}\right) = \left(\frac{x_d - y_c}{x_d - x_c}\right)$$

or, since $y_c = x_f$:

$$R_m = \left(\frac{x_d - y_c}{y_c - x_c}\right) = \left(\frac{x_d - x_f}{x_f - x_c}\right) \tag{11.50}$$

Underwood and Fenske equations

For ideal mixtures, or where over the concentration range concerned the relative volatility may be taken as constant, R_m may be obtained analytically from the physical properties of the system as discussed by Underwood[28]. Thus, if x_{nA} and x_{nB} are the mole fractions of two components **A** and **B** in the liquid on any plate n, then a material balance over the top portion of the column above plate n gives:

$$V_n y_{nA} = L_n x_{(n+1)A} + D x_{dA} \tag{11.51}$$

and:

$$V_n y_{nB} = L_n x_{(n+1)B} + D x_{dB} \tag{11.52}$$