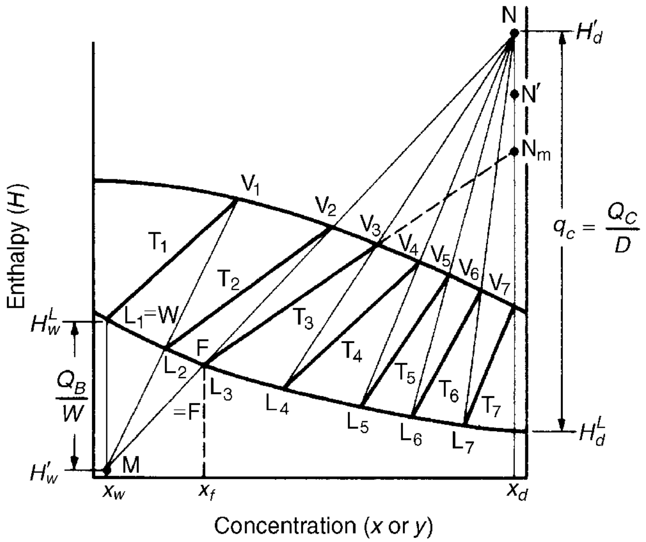

Figure 11.28. Determination of the number of plates using the enthalpy–composition diagram

The condition of the vapour leaving the top plate is shown at V_7 on the dew-point curve with abscissa x_d. The condition of the liquid on the top plate is then found by drawing the tie line T_7 from V_7 to L_7 on the boiling curve. The condition V_6 of the vapour on the second plate is found, from equation 11.77, by drawing L_7N to cut the dew-point curve on V_6. L_6 is then found on the tie line T_6. The conditions of vapour and liquid V_5, V_4, V_3 and L_5, L_4 are found in the same way. Tie line T_3 gives L_3, which has the same composition as the feed. V_2 is then found using the line MFV_2, as this represents the vapour on the top plate of the stripping section. L_2, L_1 and V_1 are then found by a similar construction. L_1 has the required composition of the bottoms, x_w.

Alternatively, calculations may start with the feed condition and proceed up and down the column.

11.5.3. Minimum reflux ratio

The pole N has coordinates $[x_d, H_d^L + Q_C/D]$. Q_C/D is the heat removed in the condenser per unit mass of product, as liquid at its boiling point and is represented as shown in Figure 11.28. The number of plates in the rectifying section is determined, for a given feed x_f and product x_d, by the height of this pole N. As N is lowered to say N′ the heat q_c falls, although the number of plates required increases. When N lies at N_m on the isothermal through F, q_c is a minimum although the number of plates required becomes infinite. Since the tie lines have different slopes, it follows that there is a minimum reflux for each plate, and the tie line cutting the vertical axis at the highest value of H will give the minimum practical reflux. This will frequently correspond to the tie line through F.

From equations 11.83 and 11.95 and writing $Q_C/D = q_c$, then:

$$\frac{H_d^L + q_c - H_n^V}{H_n^V - H_{n+1}^L} = \frac{x_d - y_n}{y_n - x_{n+1}} \tag{11.96}$$

or:

$$q_c = (H_n^V - H_{n+1}^L)\left(\frac{x_d - y_n}{y_n - x_{n+1}}\right) + H_n^V - H_d^L \tag{11.97}$$

and:

$$(q_c)_{\min} = (H_f^V - H_{f+1}^L)\left(\frac{x_d - y_f}{y_f - x_{f+1}}\right) + H_f^V - H_d^L \tag{11.98}$$

The advantage of the $H - x$ chart lies in the fact that the heat quantities required for the distillation are clearly indicated. Thus, the higher the reflux ratio the more heat must be removed per mole of product, and point N rises. This immediately shows that both q_c and Q_B are increased. The use of this method is illustrated by considering the separation of ammonia from an ammonia–water mixture, as occurs in the ammonia absorption unit for refrigeration.

Example 11.10

It is required to separate 1 kg/s (3.6 tonnes/h) of a solution of ammonia in water, containing 30 per cent by mass of ammonia, to give a top product of 99.5 per cent purity and a weak solution containing 10 per cent by mass of ammonia.

Calculate the heat required in the boiler and the heat to be rejected in the condenser, assuming a reflux 8 per cent in excess of the minimum and a column pressure of 1000 kN/m^2. The plates may be assumed to have an ideal efficiency of 60 per cent.

Solution

Taking a material balance for the whole throughput and for the ammonia gives:

$$D + W = 1.0$$

$$0.995D + 0.1W = (1.0 \times 0.3)$$

Thus: $$D = 0.22 \text{ kg/s}$$

and: $$W = 0.78 \text{ kg/s}$$

The enthalpy–composition chart for this system is shown in Figure 11.29. It is assumed that the feed F and the bottom product W are both liquids at their boiling points.

Location of the poles N *and* M

N$_\text{m}$ for minimum reflux is found by drawing a tie-line through F, representing the feed, to cut the line $x = 0.995$ at N$_\text{m}$.

$$\text{The minimum reflux ratio, } R_m = \frac{\text{length N}_\text{m}\text{A}}{\text{length AL}}$$

$$= \frac{(1952 - 1547)}{(1547 - 295)} = 0.323$$

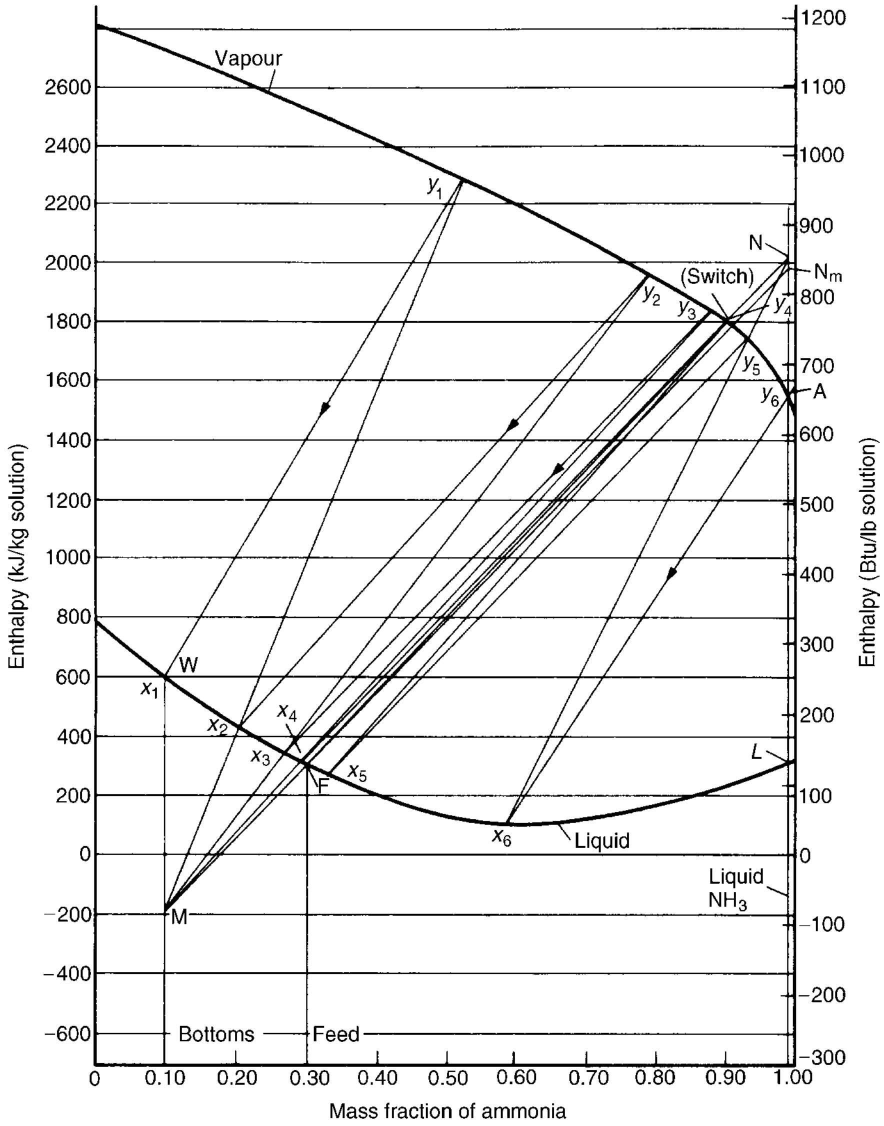

Figure 11.29. Enthalpy–composition diagram for ammonia–water at 1.0 MN/m^2 pressure (Example 11.10)

Since the actual reflux is 8 per cent above the minimum, then:

$$NA = 1.08\ N_m A$$

$$= (1.08 \times 405) = 437$$

Point N therefore has an ordinate of $(437 + 1547) = 1984$ and an abscissa of 0.995.
Point M is found by drawing NF to cut the line $x = 0.10$, through W, at M.
The number of theoretical plates is found, as on the diagram, to be 5+.

The number of plates to be provided = (5/0.6) = 8.33, say 9.

The feed is introduced just below the third ideal plate from the top, or just below the fifth actual plate.

The heat input at the boiler per unit mass of bottom product is:

$$\frac{Q_B}{W} = 582 - (-209) = 791$$

$$\text{Heat input to boiler} = (791 \times 0.78) = \underline{\underline{617\ \text{kW}}}$$

$$\begin{aligned}\text{Condenser duty} &= \text{length NL} \times D \\ &= (1984 - 296) \times 0.22 \\ &= \underline{\underline{372\ \text{kW}}}\end{aligned}$$

11.5.4. Multiple feeds and sidestreams

The enthalpy–composition approach may also be used for multiple feeds and sidestreams for binary systems. For the condition of constant molar overflow, each additional sidestream or feed adds a further operating line and pole point to the system.

Taking the same system as used in Figure 11.22, with one sidestream only, the procedure is as shown in Figure 11.30.

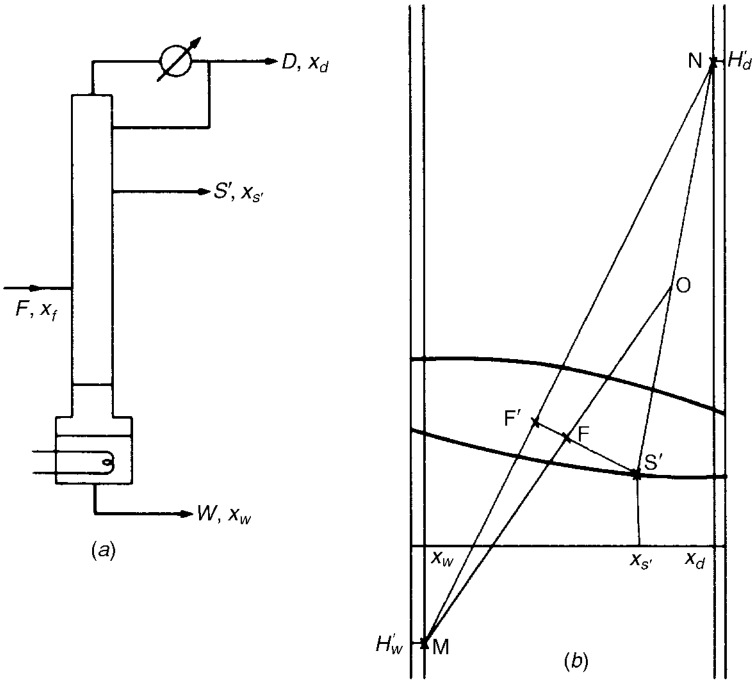

Figure 11.30. Enthalpy–composition diagram for a system with one sidestream