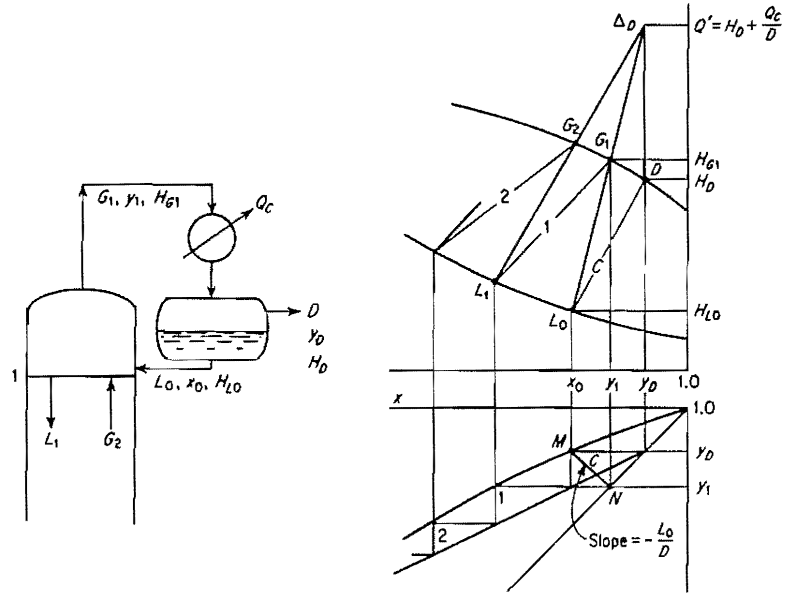


Figure 9.19 Partial condenser.

The Stripping Section

Consider the envelope IV, Fig. 9.17, where tray m is any tray in the stripping section. A balance for total material is

$$\bar{L}_m = \bar{G}_{m+1} + W \tag{9.66}$$

and, for component A,

$$\bar{L}_m x_m = \bar{G}_{m+1} y_{m+1} + W x_W \tag{9.67}$$

$$\bar{L}_m x_m - \bar{G}_{m+1} y_{m+1} = W x_W \tag{9.68}$$

The left-hand side of Eq. (9.68) represents the difference in rate of flow of component A, down − up, or the net flow downward. Since the right-hand side is a constant for a given distillation, the difference is independent of tray number in this section of the tower and equal to the rate of permanent removal of A out the bottom. An enthalpy balance is

$$\bar{L}_m H_{L_m} + Q_B = \bar{G}_{m+1} H_{G_{m+1}} + W H_W \tag{9.69}$$

Define Q'' as the net flow of heat outward at the bottom, per mole of residue

$$Q'' = \frac{WH_W - Q_B}{W} = H_W - \frac{Q_B}{W} \tag{9.70}$$

whence $$\bar{L}_m H_{L_m} - \bar{G}_{m+1} H_{G_{m+1}} = WQ'' \tag{9.71}$$

The left-hand side of Eq. (9.71) is the difference in rate of flow of heat, down − up, which then equals the constant net rate of heat flow out the bottom for all trays in this section.

Elimination of W between Eqs. (9.66) and (9.67) and between Eqs. (9.66) and (9.71) provides

$$\frac{\bar{L}_m}{\bar{G}_{m+1}} = \frac{y_{m+1} - x_W}{x_m - x_W} = \frac{H_{G_{m+1}} - Q''}{H_{L_m} - Q''} \tag{9.72}$$

On the Hxy diagram, Eq. (9.72) is a straight line through $(H_{G_{m+1}}, y_{m+1})$ at $\bar{G}_{m+1}$, (H_{L_m}, x_m) at $\bar{L}_m$, and (Q'', x_W) at Δ_W. Δ_W is a *difference* point, whose coordinates mean

$$\Delta_W \begin{cases} Q'' = \dfrac{\text{difference in heat flow, down} - \text{up}}{\text{net moles of total substance out}} = \dfrac{\text{net heat out}}{\text{net moles out}} \\ x_W = \dfrac{\text{difference in flow of component A, down} - \text{up}}{\text{net moles of total substance out}} = \dfrac{\text{moles A out}}{\text{net moles out}} \end{cases}$$

Thus, Δ_W is a fictitious stream, in amount equal to the net flow outward (in this case W), of properties (Q'', x_W),

$$\bar{L}_m - \bar{G}_{m+1} = \Delta_W \tag{9.73}$$

On the xy diagram, Eq. (9.72) is a straight line of slope $\bar{L}_m/\bar{G}_{m+1}$, through (y_{m+1}, x_m) and $y = x = x_W$. These straight lines are plotted in Fig. 9.20 for both diagrams.

Since Eq. (9.72) applies to all trays of the stripping section, the line on the Hxy plot of Fig. 9.20 from $\bar{G}_{N_p+1}$ (vapor leaving the reboiler and entering the bottom tray N_p of the tower) to Δ_W intersects the saturated-liquid-enthalpy curve at $\bar{L}_{N_p}$, the liquid leaving the bottom tray. Vapor $\bar{G}_{N_p}$ leaving the bottom tray is in equilibrium with liquid $\bar{L}_{N_p}$ and is located on the tie line N_p. Tie lines projected to the xy diagram produce points on the equilibrium curve, and lines through Δ_W provide points such as T on the operating curve. Substitution of Eq. (9.66) into Eq. (9.72) provides

$$\frac{\bar{L}_m}{W} = \frac{H_{G_{m+1}} - Q''}{H_{G_{m+1}} - H_{L_m}} = \frac{y_{m+1} - x_W}{y_{m+1} - x_m} \tag{9.74}$$

The diagrams have been drawn for the type of reboiler shown in Fig. 9.17, where the vapor leaving the reboiler is in equilibrium with the residue, the reboiler thus providing an equilibrium stage of enrichment (tie line B, Fig. 9.20). Other methods of applying heat at the bottom of the still are considered later.

Stripping-section trays can thus be determined entirely on the Hxy diagram by alternating construction lines to Δ_W and tie lines, each tie line accounting for an equilibrium stage. Alternatively, random lines radiating from Δ_W can be drawn, their intersections with curves $H_G y$ and $H_L x$ plotted on the xy diagram

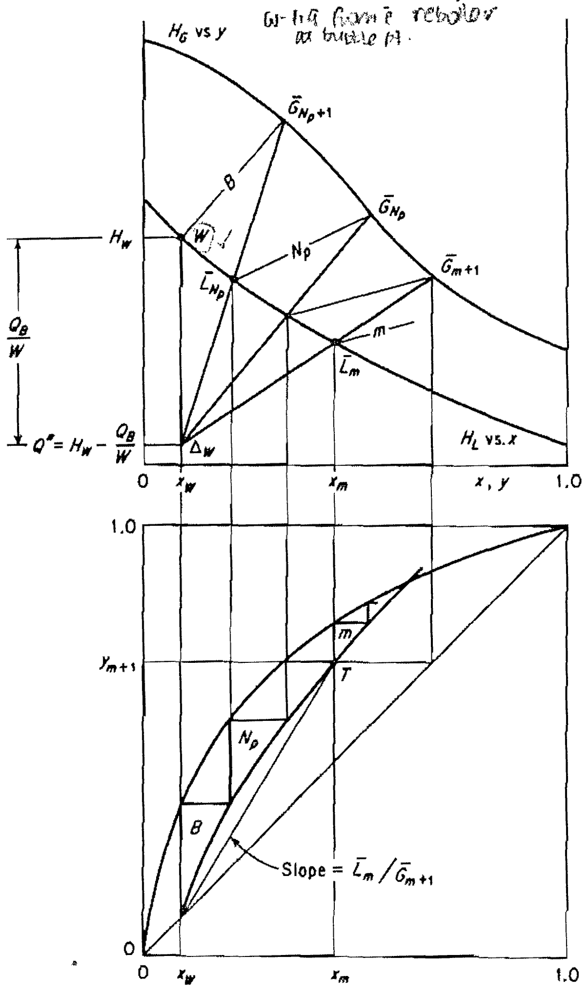


Figure 9.20 Stripping section.

to produce the operating curve, and the stages determined by the usual step construction.

The Complete Fractionator

Envelope II of Fig. 9.17 can be used for material balances over the entire device

$$F = D + W \tag{9.75}$$

$$Fz_F = Dz_D + Wx_W \tag{9.76}$$

Equation (9.55) is a complete enthalpy balance. If, in the absence of heat losses

($Q_L = 0$), the definitions of Q' and Q'' are substituted into Eq. (9.55), it becomes

$$FH_F = DQ' + WQ'' \tag{9.77}$$

If F is eliminated from Eqs. (9.75) to (9.77), there results

$$\frac{D}{W} = \frac{z_F - x_W}{z_D - z_F} = \frac{H_F - Q''}{Q' - H_F} \tag{9.78}$$

This is the equation of a straight line on the Hxy diagram, through (Q', z_D) at Δ_D, (H_F, z_F) at F, and (Q'', x_W) at Δ_W, as plotted in Fig. 9.21. In other words,

$$F = \Delta_D + \Delta_W \tag{9.79}$$

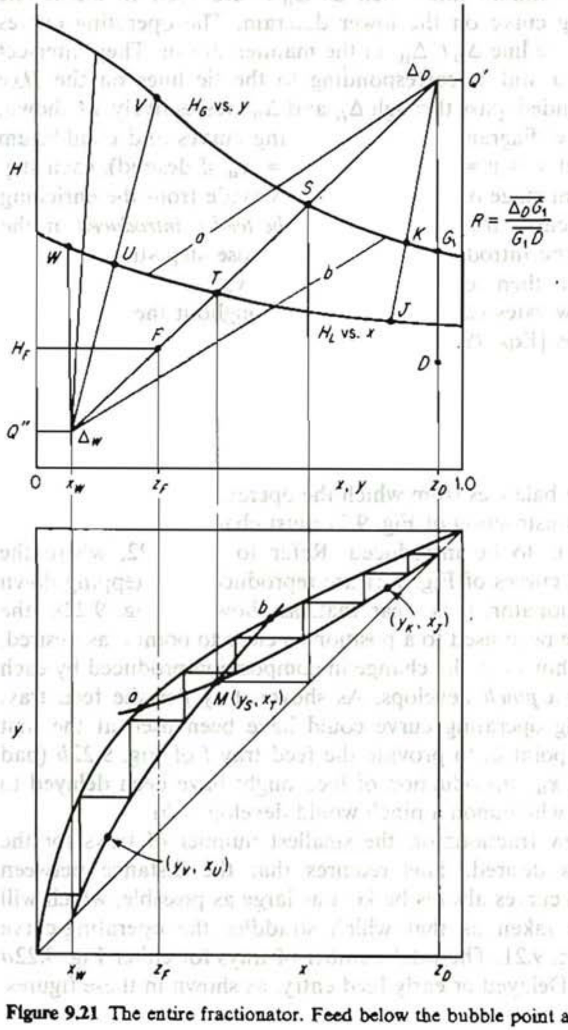


Figure 9.21 The entire fractionator. Feed below the bubble point and a total condenser.

The location of F, representing the feed, on Fig. 9.21 shows the feed in this case to be a liquid below the bubble point. In other situations, F may be on the saturated-liquid or vapor curve, between them, or above the saturated-vapor curve. In any event, the two Δ points and F must lie on a single straight line.

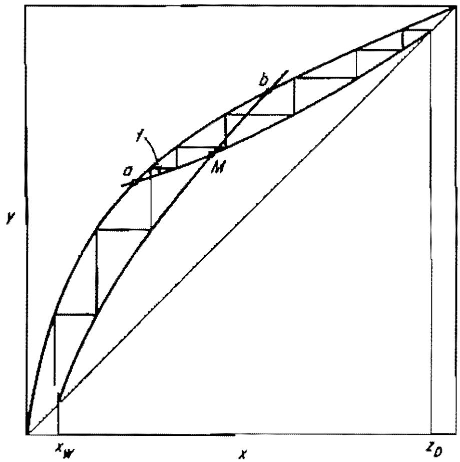
The construction for trays is now clear. After locating F and the concentration abscissas z_D and x_W corresponding to the products on the Hxy diagram, Δ_D is located vertically on line $x = z_D$ by computation of Q' or by the line-length ratio of Eq. (9.65) using the specified reflux ratio R. The line $\Delta_D F$ extended to $x = x_W$ locates Δ_W, whose ordinate can be used to compute Q_B. Random lines such as $\Delta_D J$ are drawn from Δ_D to locate the enriching-section operating curve on the xy diagram, and random lines such as $\Delta_W V$ are used to locate the stripping-section operating curve on the lower diagram. The operating curves intersect at M, related to the line $\Delta_D F \Delta_W$ in the manner shown. They intersect the equilibrium curve at a and b, corresponding to the tie lines on the Hxy diagram which, when extended, pass through Δ_D and Δ_W, respectively, as shown. Steps are drawn on the xy diagram between operating curves and equilibrium curve, beginning usually at $x = y = z_D$ (or at $x = y = x_W$ if desired), each step representing an equilibrium stage or tray. A change is made from the enriching to the stripping operating curve *at the tray on which the feed is introduced*; in the case shown the feed is to be introduced on the tray whose step straddles point M. The step construction is then continued to $x = y = x_W$.

Liquid and vapor flow rates can be computed throughout the fractionator from the line-length ratios [Eqs. (9.62), (9.64), (9.72), and (9.74)] on the Hxy diagram.

Feed-Tray Location

The material and enthalpy balances from which the operating curves are derived dictate that the stepwise construction of Fig. 9.21 must change operating lines at the tray where the feed is to be introduced. Refer to Fig. 9.22, where the equilibrium and operating curves of Fig. 9.21 are reproduced. In stepping down from the top of the fractionator, it is clear that, as shown in Fig. 9.22*a*, the enriching curve could have been used to a position as close to point a as desired. As point a is approached, however, the change in composition produced by each tray diminishes, and at a a *pinch* develops. As shown, tray f is the feed tray. Alternatively, the stripping operating curve could have been used at the first opportunity after passing point b, to provide the feed tray f of Fig. 9.22*b* (had the construction begun at x_W, introduction of feed might have been delayed to as near point b as desired, whereupon a pinch would develop at b).

In the design of a new fractionator, the smallest number of trays for the circumstances at hand is desired. This requires that the distance between operating and equilibrium curves always be kept as large as possible, which will occur if the feed tray is taken as that which straddles the operating-curve intersection at M, as in Fig. 9.21. The total number of trays for either Fig. 9.22*a* or b is of necessity larger. Delayed or early feed entry, as shown in these figures,



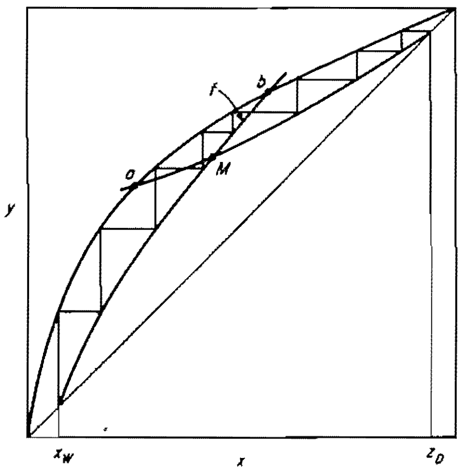


Figure 9.22 Delayed and early feed entries.

is used only where a separation is being adapted to an existing tower equipped with a feed-tray entry nozzle on a particular tray, which must then be used.

Consider again the feed tray of Fig. 9.21. It is understood that if the feed is all liquid, it is introduced above the tray in such a manner that it enters the tray along with the liquid from the tray above. Conversely, if the feed is all vapor, it is introduced underneath the feed tray. Should the feed be mixed liquid and vapor, in principle it should be separated outside the column and the liquid portion introduced above, the vapor portion below, the feed tray. This is rarely