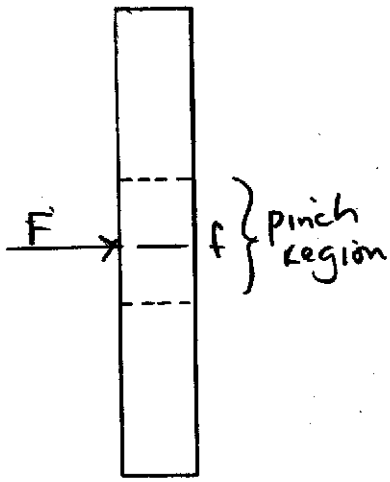
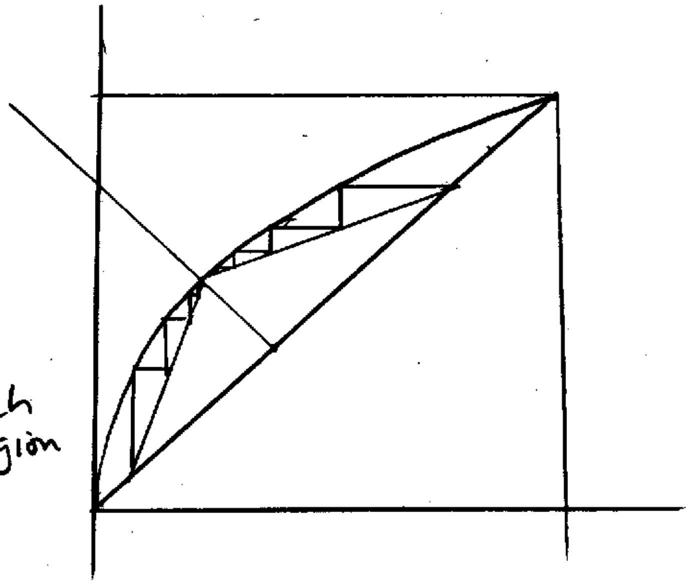
6-6





For binary distillation, the pinch region occurs near the feed stage.

This is also the case for LK and HK MC distillation, however NK's tend to pinch away from the feed stage.

The situation of pinches in MCD has been broken into 2 classes

Class 1 - narrow boiling mixture or unsharp separations (hence, all components tending to distribute.

Class 2 - wide boiling mixtures or sharp separations (hence, NK's do not distribute.)

(6-7)

For class 2, HNK's pinch in the top
LNK's " " " bottom.

Key Principle - In the pinch region, compositions do not vary from stage to stage.

Analysis

In rectifying section,

$$y_{i\infty} V_\infty = x_{i\infty} L_\infty + x_{iD} D \qquad 9\text{-}17$$

∞ = pinch conditions

Also $V_\infty = L_\infty + D \qquad 9\text{-}18$

and $y_{i\infty} = x_{i\infty} K_{i\infty} \qquad 9\text{-}19$

Combining 9-17 — 9-19 and employing the definition of α,

$$\frac{L_\infty}{D} = \frac{(x_{iD}/x_{i\infty}) - (\alpha_{ij})_\infty \left(\frac{x_{jD}}{x_{j\infty}}\right)}{(\alpha_{ij})_\infty - 1}$$

For class 1 separations, pinches occur at the feed stage and feed conditions therefore

$$\left(\frac{L_\infty}{D}\right)_{min} = \left(\frac{L_F}{F}\right) \frac{\left[(D x_{LK,D})(L_F x_{LK\,F}) - (\alpha_{LK,HK})_F \ldots\right]}{(\alpha_{LKHK})_F - 1}$$

6-8 $\ldots \left(D X_{HKD} / L_F X_{HKF}\right)\Big]$ (9-21)

Equation 9-21 is attributed to Underwood.

If necessary L_F & X_{iF} can be adjusted to account for subcooled or superheated feeds.

As with the Fenske Eqxn, once $\left(\frac{L}{D}\right)_{min}$ has be determined, one can back calculate the distribution of othere NK materials by eliminating either LK or HK $\rightarrow$ i or j:

Eqxn 9-22 shows this for LK $\rightarrow i$

We can also perform an enthalpy balance for class 1 separations around the rectifying section provides

$$\left(\frac{L_{min}}{D}\right) = R_{min} = \frac{(L_\infty)_{min}\left(h_{V_\infty} - h_{L_\infty}\right) + D\left(h_{V_\infty} - h_V\right)}{D\left(h_V - h_L\right)}$$

9-23

where V & L refer to vapor leaving stage 1 and reflux liquid entering.

6-9 For class 2 separations, we have a more complicated situations.

Eqxns (9-17) – (9-20) still apply but not (9-21) since the pinch does not occur at the known feed conditions.

Underwood showed for these conditions

Rectifying section
$$\sum \frac{(\alpha_{ix})_\infty x_{iD}}{(\alpha_{ix})_\infty - \phi} = 1 + R_{\infty\,min} \qquad (9\text{-}24)$$

x = ref. component (select as HK!)

Stripping section
$$\sum \frac{(\alpha'_{ix})_\infty x_{iB}}{(\alpha'_{ix})_\infty - \phi'} = 1 - R'_{\infty\,min} \qquad (9\text{-}25)$$

where $R'_{\infty\,min} = \dfrac{L'_\infty}{B}$

" ' " conditions at stripping pinch

Underwoods analysis has two critical assumptions

(1) common relative volatility between two pinch zones $\alpha = \alpha'$

6-10

(2) $R_{\infty\, min}$ relates to $R'_{\infty\, min}$ by CMO

Hence $L'_{\infty\, min} - L_{\infty\, min} = qF$ (9-26)

Eqxn (9-24) & (9-25) are a series of terms, therefore having roots in terms of the parameter ϕ and ϕ'

Underwood showed a "common root" is appropriate $\theta = \phi = \phi'$

Adding (9-24) to (9-25) and applying

$$z_{iF} F = x_{iD} D + x_{iB} B$$

Underwood obtained

$$\sum \frac{(\alpha_{ir})_\infty z_{iF}}{(\alpha_{ir})_\infty - \theta} = 1 - q \qquad (9\text{-}28)$$

2nd underwood eqxn

(9-28) is solved for θ

where $\alpha_{LK,HK} > \theta > 1$

6-11

Then these values are placed in (9-24) in the form of

$$\sum \frac{(\alpha_{ik})_\infty x_{iD}}{(\alpha_{ik})_\infty - \theta} = 1 + (R_\infty)_{min}$$

alternate presentation

Let $\phi = \dfrac{L_{min}}{V_{min} K_{HK}}$ $\quad \bar{\phi} = \dfrac{\bar{L}_{min}}{\bar{V}_{min} \bar{K}_{HK}}$

$$V_{min} = \sum \frac{\alpha_i D x_{iD}}{\alpha_i - \phi} \qquad (A)$$

$$-\bar{V}_{min} = \sum \frac{\bar{\alpha}_i B x_{iB}}{\bar{\alpha}_i - \bar{\phi}} \qquad (B)$$

$$\phi = \bar{\phi} = \theta \qquad \alpha_i = \bar{\alpha}_i = \alpha_{ik} \leftarrow HK$$

$$V_{min} - \bar{V}_{min} = \sum \left[\frac{\alpha_i D x_{iD}}{\alpha_i - \theta} + \frac{\alpha_i B x_{iB}}{\alpha_i - \theta} \right] \qquad (C)$$

$$\therefore \Delta V_{feed} = \sum \frac{\alpha_i F z_i}{\alpha_i - \theta} = F(1-q) \qquad (D)$$

also $L_{min} = V_{min} - D$ (F)

6-12

General technique

(1) Use (D) to find θ

(2) Use (A) to find V_{min}

(3) Use (F) to find L_{min}

(4) $R_{min} = \dfrac{L_{min}}{D}$

Example

Suppose $c = 2$ w/ sat'd liquid feed.

$$\therefore \quad 0 = \frac{\alpha_a F z_a}{\alpha_a - \theta} + \frac{\alpha_b F z_b}{\alpha_b - \theta}$$

$$\theta = \frac{\alpha_a \alpha_b}{\alpha_a z_a + \alpha_b z_b}$$

(note, normally θ is found by trial & error)

Find $V_{min} = \sum \dfrac{\alpha_a D x_{iD}}{\alpha_a - \theta}$

Find $L_{min} = V_{min} - D$

from all or nothing or Fenske

6-13

When a "a priori" knowledge of the distribution of all NK's is not available the underwood method can be employed to develop C-1 θ's in C-1 eqxn's of type "A" which are solved simultaneously.

Solutions of this sort will not be tested on.

Note: When single values of θ are to be determined, they always lie between $\alpha_{HK} < \theta < \alpha_{LK}$

Gilliland Correlation

Actual operating columns employ reflux ratios greater than the minimum as determined by economic considerations

Various ratios are suggested in the text including

$$L/D = f\,(L/D)_m \qquad f = \begin{array}{l} 1.05 \\ 1.10 \\ 1.30 \\ 1.50 \end{array}$$

6-14

- Gilliland's correlation is based on 61 data points from the following range of parameters;

  $2 \leq C \leq 11$

  $0.28 \leq q \leq 1.42$

  $0 < p < 600$ psig

  $1.11 < \alpha < 4.05$

  $0.53 < R_{min} < 9.09$

  $3.4 < N_{min} < 60.3$

- Figure 9.10 (p509) shows the data values and the curve fit

$$Y = \frac{N - N_{min}}{N+1} = 1 - \exp\left[\left(\frac{1+54.4X}{11+117.2X}\right)\left(\frac{X-1}{X^{0.5}}\right)\right] \qquad (9\text{-}34)$$

where

$$X = \frac{R - R_{min}}{R+1}$$

- Figure 9.11 (p510) shows the same equation on rectangular coordinates.

6-15

Shortcut methods are also available to determine feed stage location.

From the Fenske equation

rec

$$\frac{N_R}{N_S} = \frac{(N_R)_{min}}{(N_S)_{min}} = \frac{\log\left[\left(\frac{x_{LK\,D}}{z_{LK\,F}}\right)\left(\frac{z_{HK\,F}}{x_{HK\,D}}\right)\right] \log(\alpha_B \alpha_F)^{1/2}}{\log\left[\left(\frac{z_{LK\,F}}{x_{LK\,B}}\right)\left(\frac{x_{HK\,B}}{z_{HK\,F}}\right)\right] \log(\alpha_D \alpha_F)^{1/2}} \quad (9\text{-}35)$$

strip

The correlation of Kirkbride provides better results

$$\frac{N_R}{N_S} = \left[\left(\frac{z_{HK\,F}}{z_{LK\,F}}\right)\left(\frac{x_{LK\,B}}{x_{HK\,D}}\right)^2\left(\frac{B}{D}\right)\right]^{0,206} \quad (9\text{-}36)$$