Multicomponent Distillation

Separation Processes Technology Lecture

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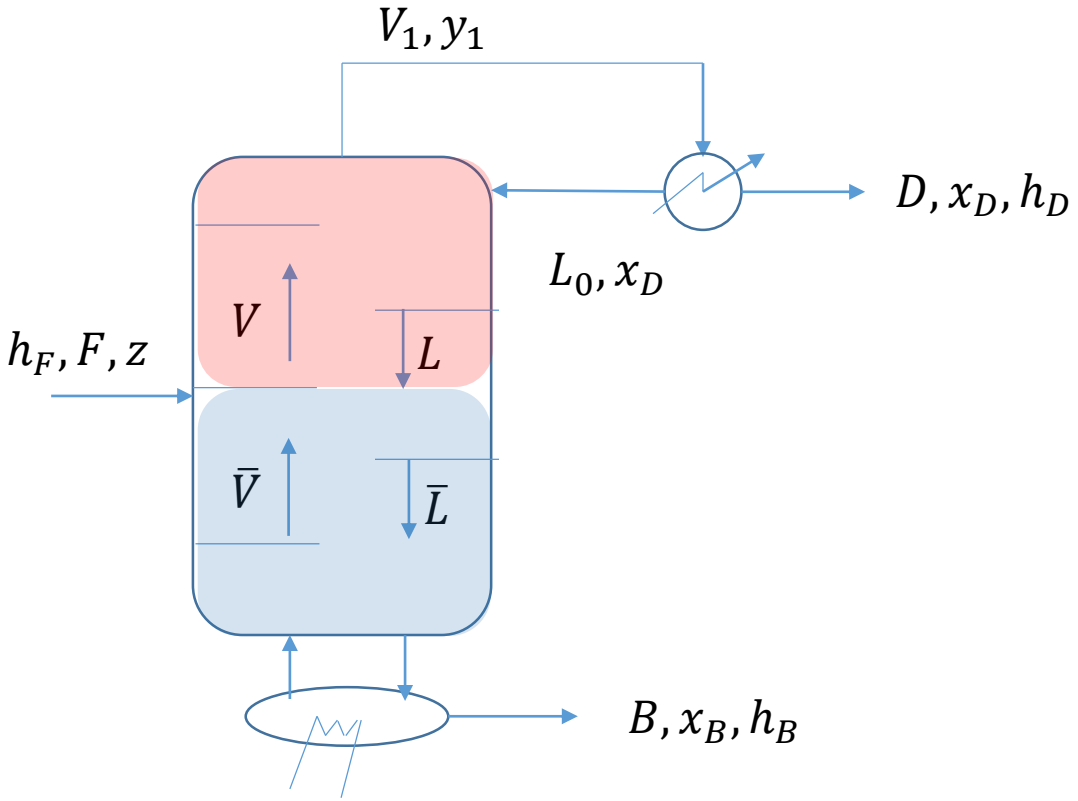
Recap Binary Distillation



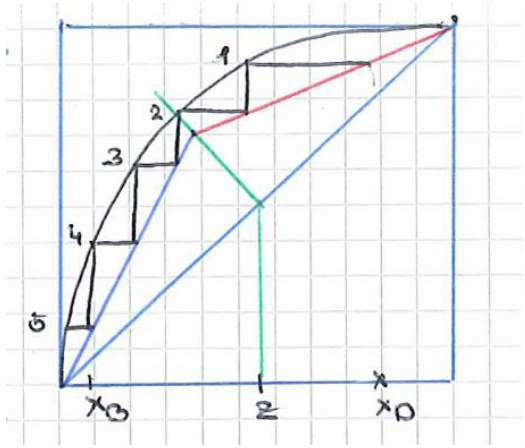
Working line rectifying section:

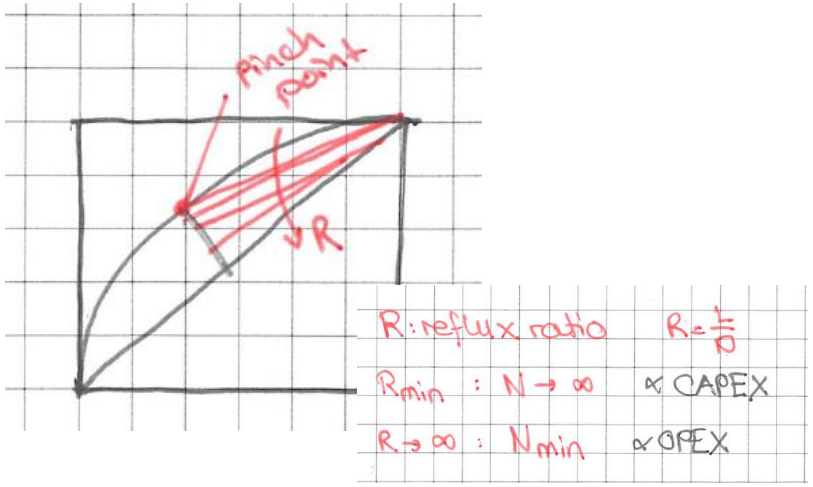
$$y = \frac{L}{V}x + \frac{D}{V}x_D$$

Working line stripping section:

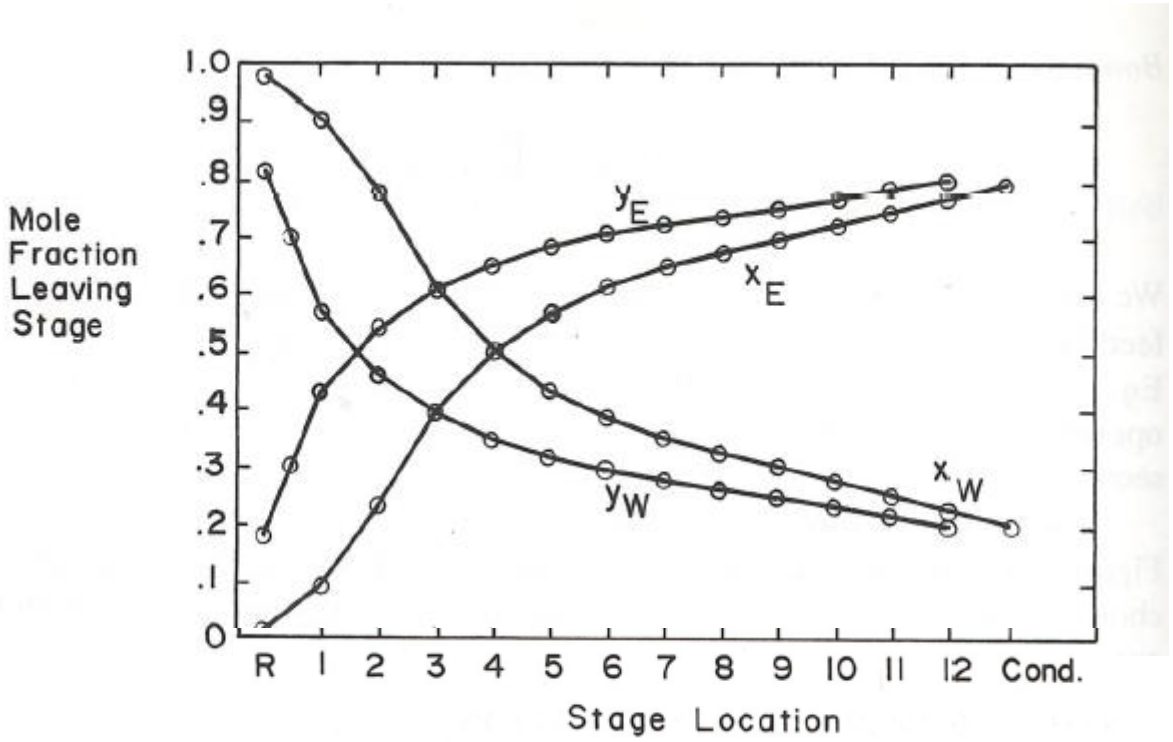
$$y = \frac{\bar{L}}{\bar{V}}x - \frac{B}{\bar{V}}x_B$$

McCabe Thiele





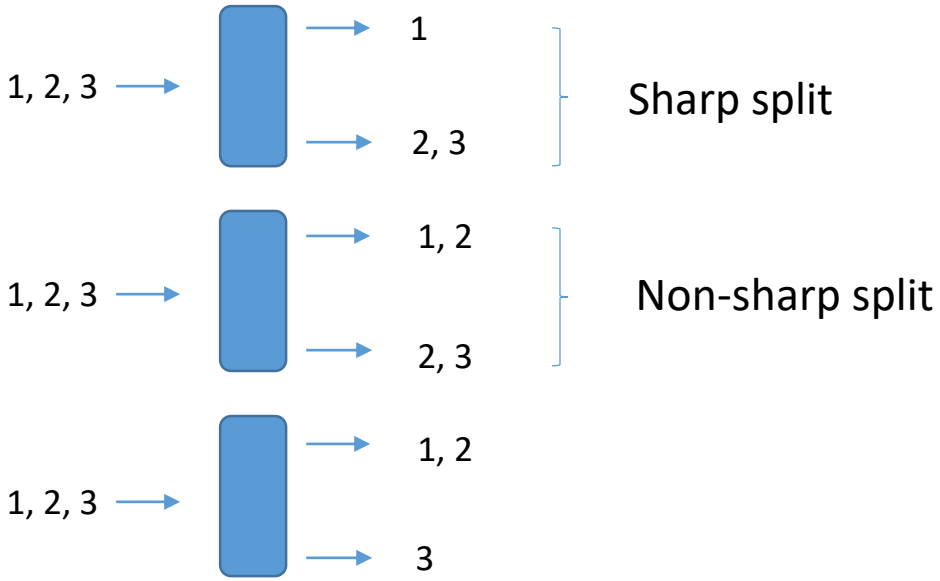
Binary Distillation Profiles

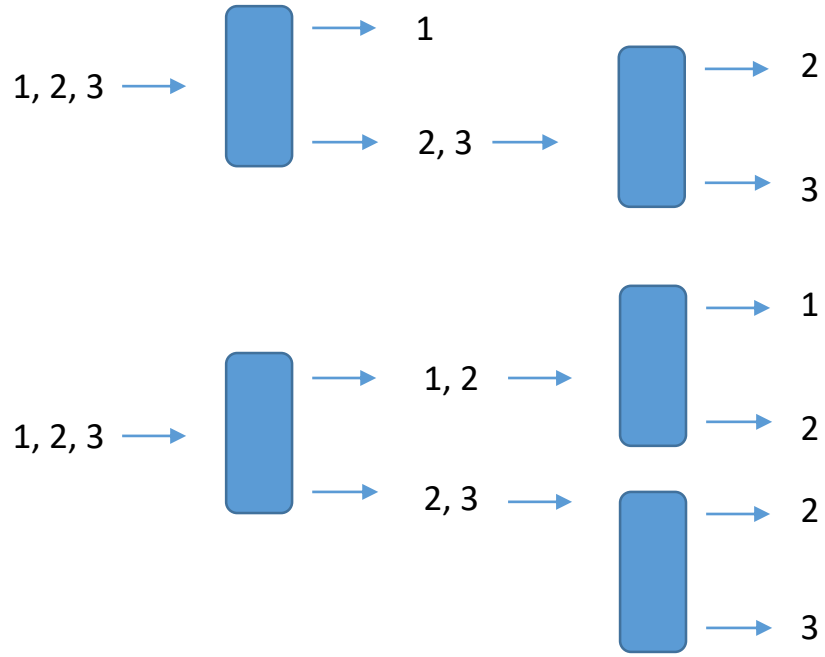


- E: EtOH, W: H2O
- Water **concentration** in both liquid and vapor streams **decreases monotonically** as we go up the column, while EtOH increases

Multicomponent Distillation

Example with three components:

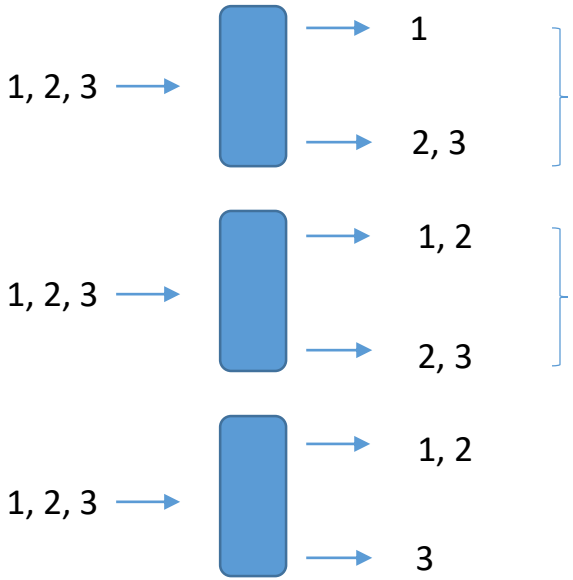




One can still add more columns to separate the rest

Multicomponent Distillation

Example with three components:



$p_3^{\mathrm{v}} < p_2^{\mathrm{v}} < p_1^{\mathrm{v}}$

3 heavier than 1

Sharp split:

1
2
…
LK

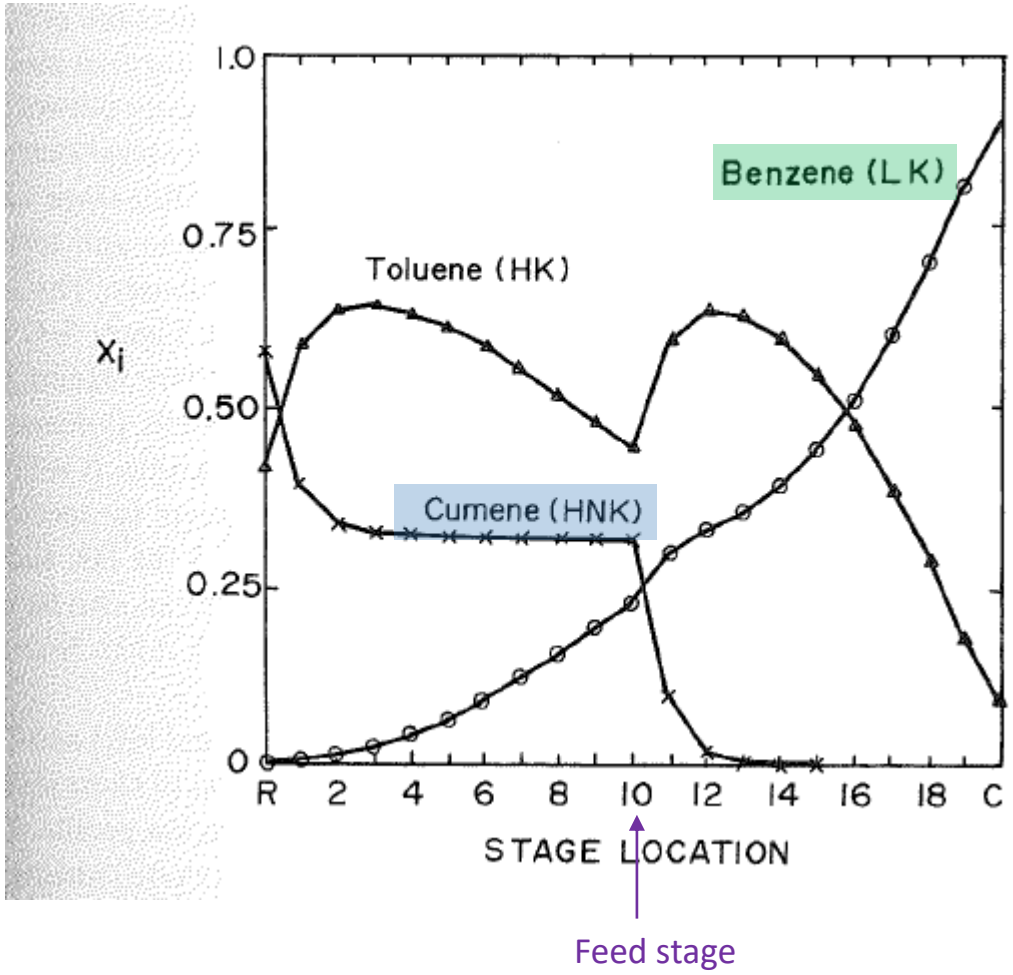
HK
…
C

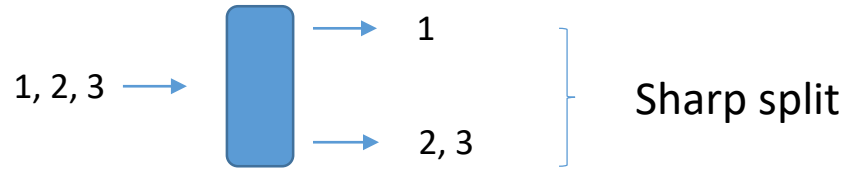
Non-sharp split:

1
2
…
Light non-key (LNK)
LK
…
HK
…
C
Heavy non-key (HNK)

- Light key (LK): most volatile of the keys
- Heavy key (HK): least volatile of the keys
- Non-keys (NK): other components
  - Light non-key (LNK): non-key that is more volatile (lighter) than the light key
  - Heavy non-key (HNK): non-key that is less volatile (heavier) than heavy key

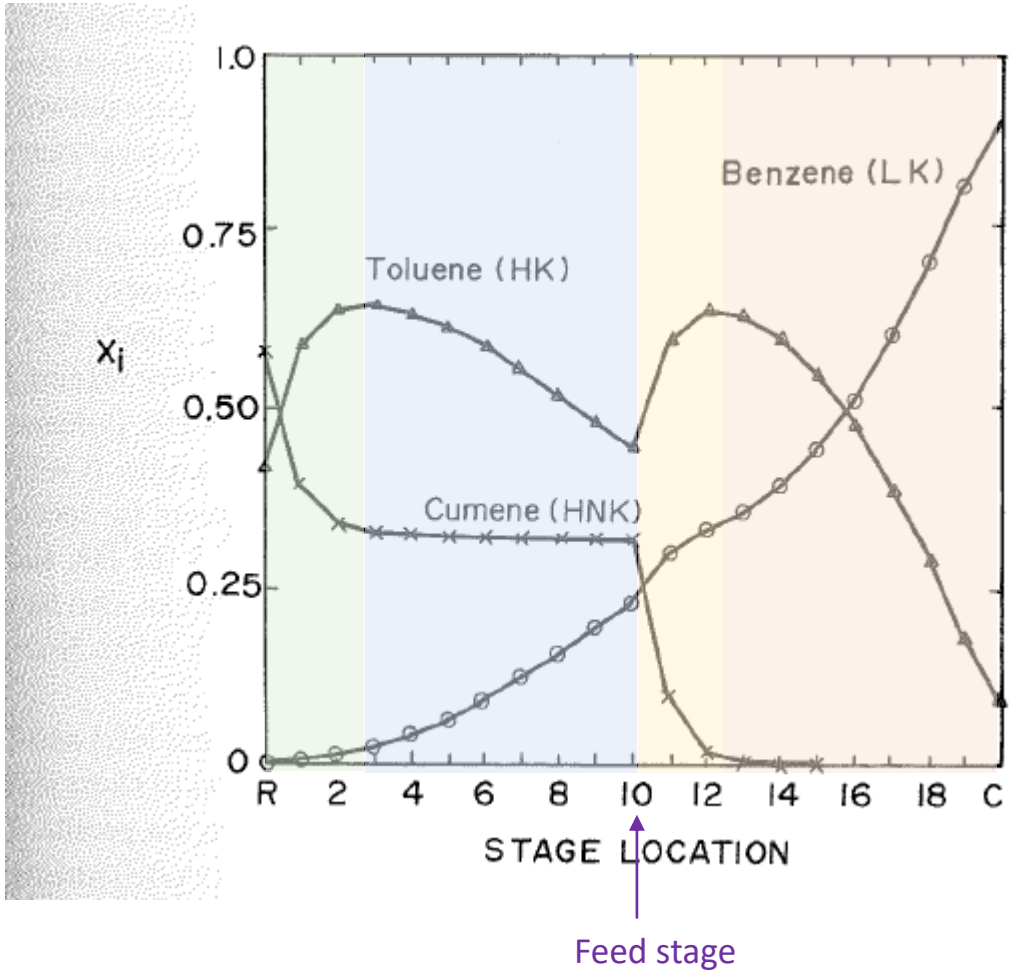
Profiles for Multicomponent Distillation with HNK





- Feed stage: 10
- LK: benzene, HK: toluene, HNK: cumene
- Benzene (LK):
  - LK, specification: 99% of recovery in distillate
  - Low mole fraction in reboiler and increases monotonically to a high value in the total condenser (same as more volatile component in binary distillation)
- Cumene (HNK):
  - Cumene leaves the column in the bottom
  - Above the feed stage, the cumene mole fraction decreases rapidly

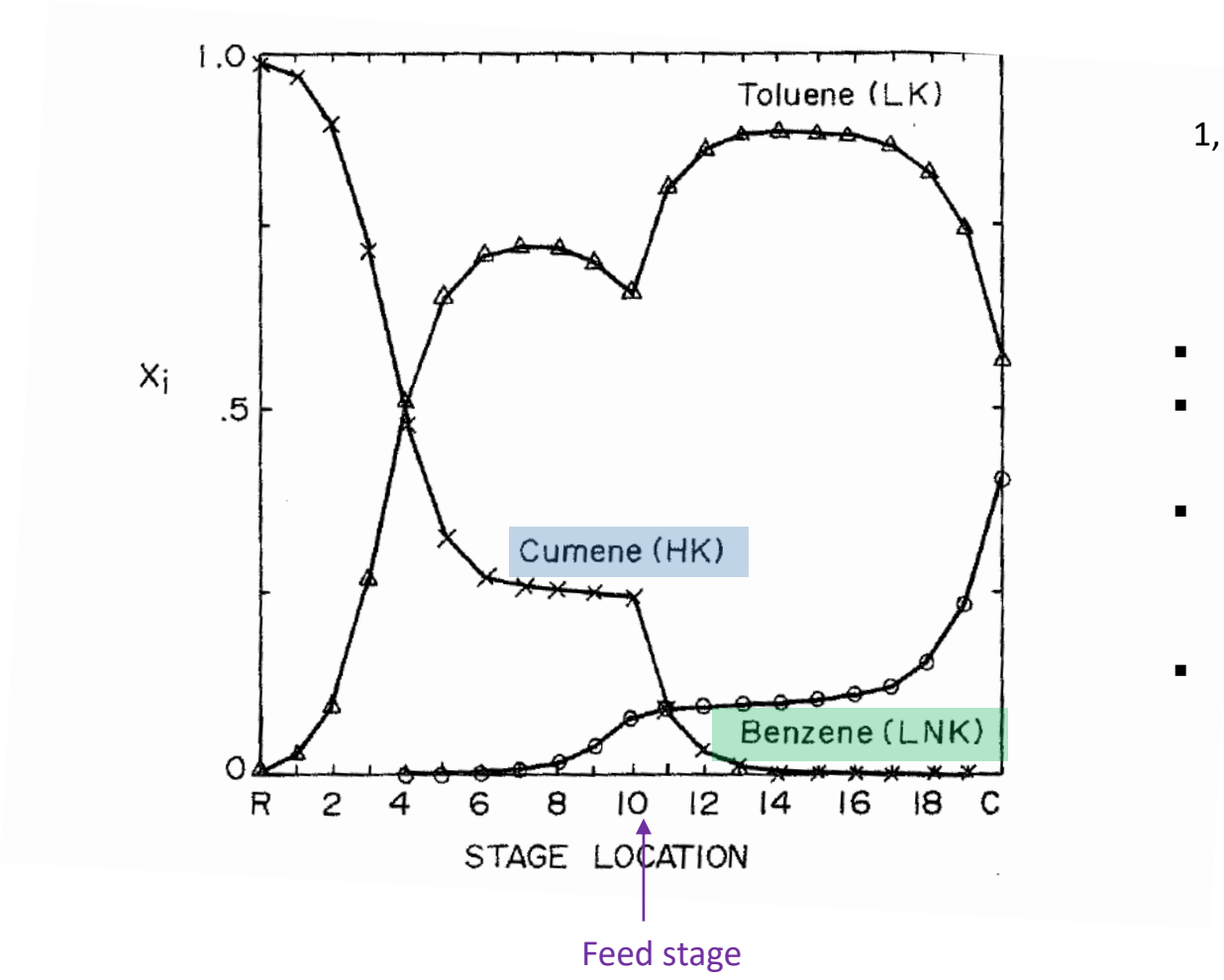
Profiles for Multicomponent Distillation with HNK

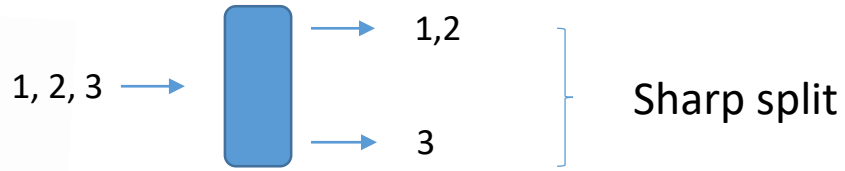


- Toluene (HK):
  - Can be explained by noting which **binary pairs of components are distilling** in each part of the column.
  - Reboiler, Stage 1 and 2: very little benzene, distillation is between HK and HNK
    -> toluene concentration increases as we go up the column because toluene is the more volatile of the two components distilling
  - Stage 3-10: cumene concentration plateaus, distillation is between the LK and HK
    -> toluene being the less volatile component leads to its decrease in concentration (causing primary maximum)
  - Above feed stage (11, 12, 13): HNK concentration plummets, distillation between HK/HNK
    -> HK is more volatile and its concentration increases
  - Above 13: distillation between HK and LK
    -> HK is less volatile and its concentration decreases (second maximum)

Cumene (HNK) causes two maxima in toluene (HK) concentration profile.

Profiles for Multicomponent Distillation with LNK



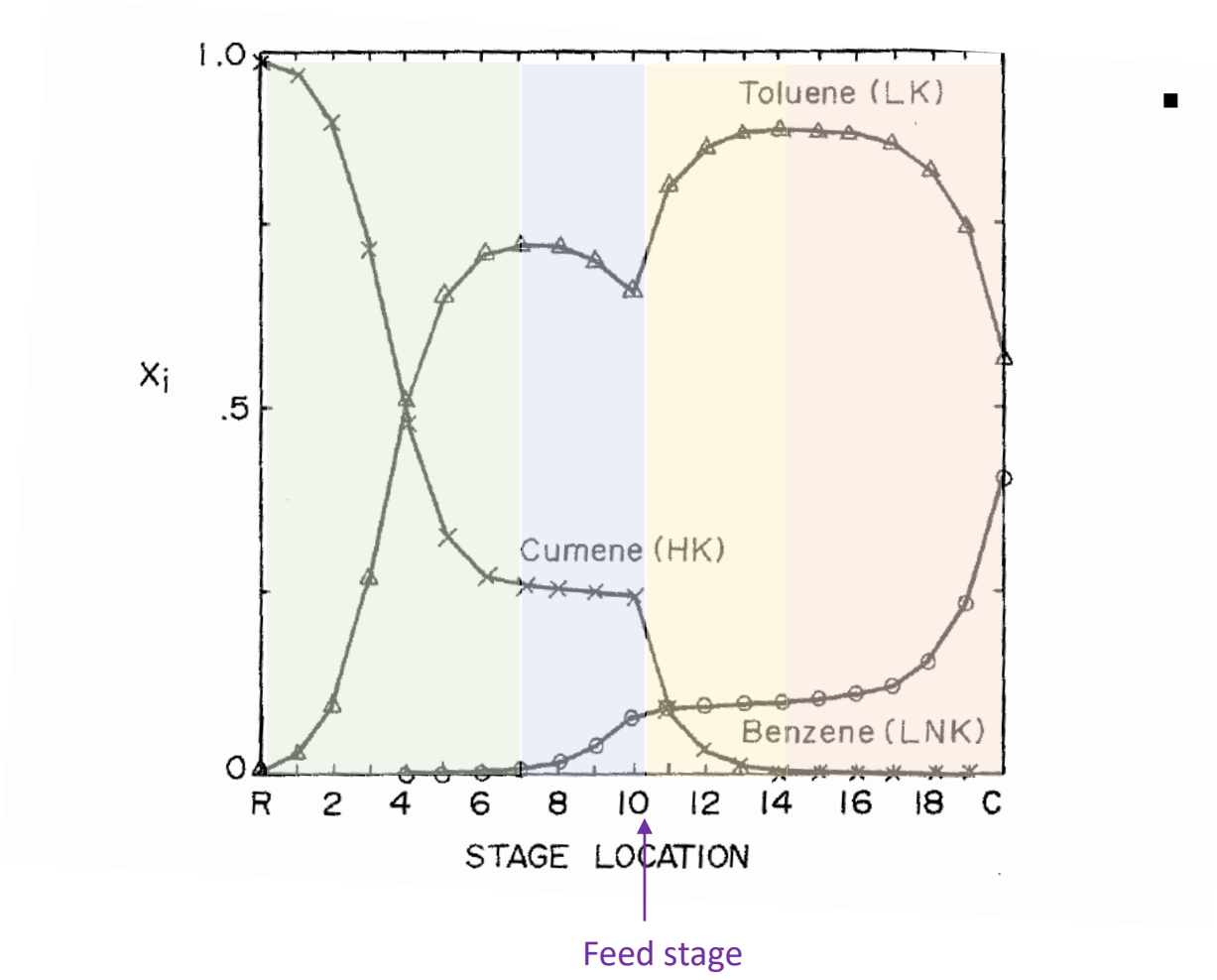


- Recovery of toluene 99% in distillate
- LK: toluene, HK: cumene, LNK: benzene

- Cumene (HK):
  - Since there is no HNK, cumene curve has no maxima

- Benzene (LNK):
  - Increases along the column with maximum at the condenser

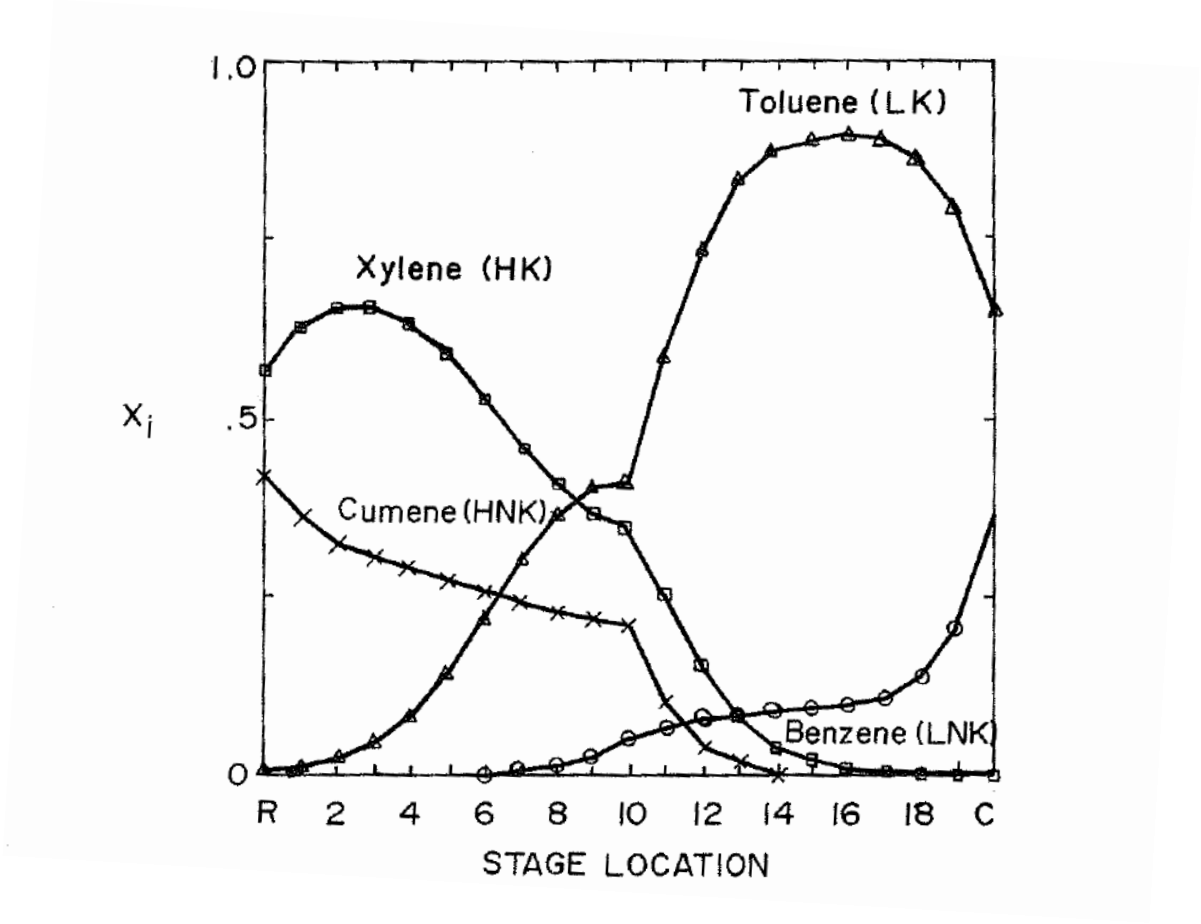
Profiles for Multicomponent Distillation with LNK

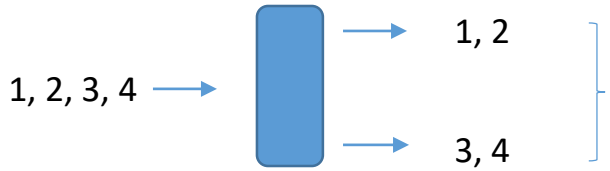


- Toluene (LK)
  - Explained with binary pairs
  - R-7: distillation between toluene and cumene -> toluene is LK and concentration increases
  - 7-10: cumene concentration pleateaus, separation between toluene and benzene -> benzene is lighter, and toluene concentration decreases (first maximum)
  - 10-14: after feed stage, cumene concentration decreases, separation between cumene and toluene -> toluene concentration increases
  - 15-C: separation between benzene and toluene -> benzene is lighter, and toluene concentration decreases (second maximum)

LNK causes two maxima in LK concentration profile.

Profiles for Multicomponent Distillation with LNK and HNK



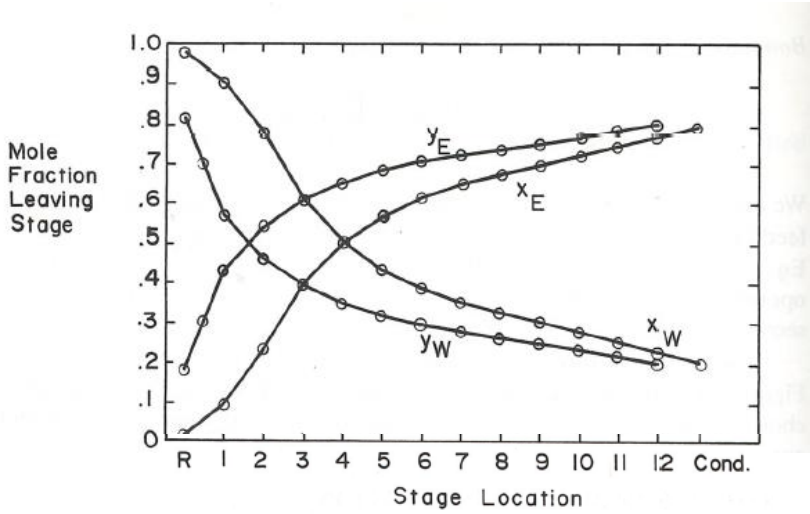


Sharp split

- Four component distillation with LNKs and HNKs
- LNK causes maxima in LK concentration profile
- HNK causes maxima in HK concentration profile
- Secondary maximum drastically repressed near the feed stage, but primary maximum well visible

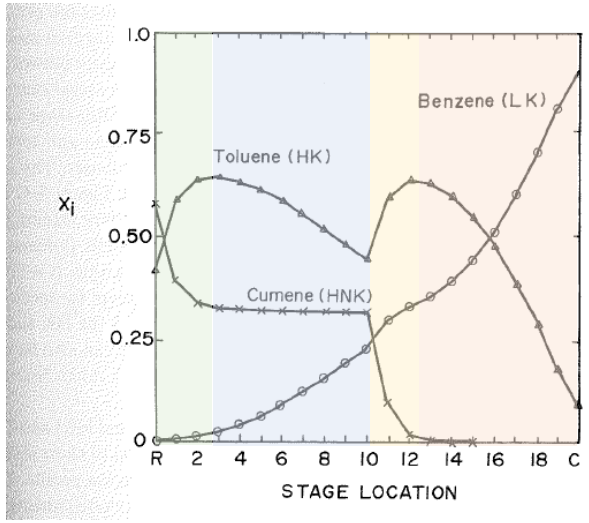
Summary Multicomponent Distillation

Binary Distillation:



Concentration in both liquid and vapor streams **decreases/increases monotonically**

Multicomponent Distillation:

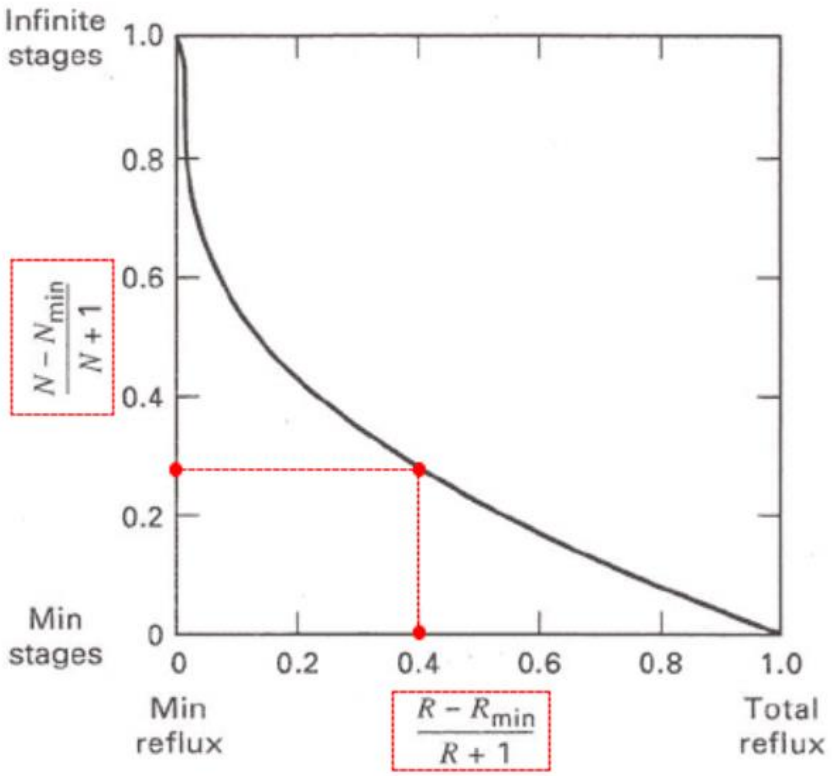


Concentration profiles not anymore monotonic.

Summary Shortcut Methods for Multicomponent Distillation:

- Fenske to get $N_{\min}$ ($R \to \infty$)
- Underwood method to get $R_{\min}$ ($N \to \infty$)
- Calculate finite reflux: $R = (1.05 - 2)R_{\min}$
- Gilliland to get $N = f(R, R_{\min}, N_{\min})$

Gilliland Method



- Gilliland used an empirical correlation to calculate the final number of stage *N* from the values calculated through the Fenske and Underwood equations (N_{min}, R, R_{min}).
- The procedure is really simple and uses a diagram as the one shown.
- One enters the diagram with the abscissa value, which is known, and read the ordinate of the corresponding point on the Gilliland curve.
- The only unknown of the ordinate is the number of stage *N*.

Gilliland Method