CE 407 Notes

Multicomponent distillation performance models

General comments

Really good book: Doherty MF, Malone MF. 2001. Conceptual design of distillation systems. McGraw-Hill, New York.

Any distillation process always has 4 degrees of freedom (things you can choose); once they are chosen the distillation is completely specified/determined

Design model/calculation

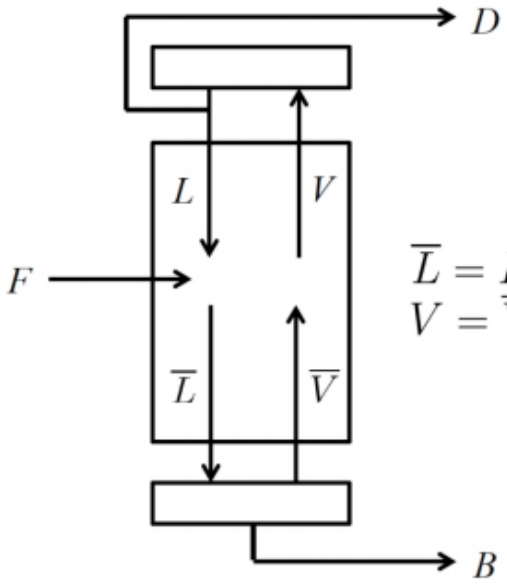
"Boundary value design method," what you have always done until now

Choose x_D, x_B, $R = L/D$ and optimal feed location (suboptimal feed location is possible)

Graphical calculation of N (might not come out to be an integer); N and feed tray number → N_r and N_s; 'nuff sed…

Performance model/calculation

This is a prediction of what will emerge from a completely specified distillation column. It is what is usually done by a process simulator.



$$\overline{L} = L + qF$$
$$V = \overline{V} + (1-q)F$$

Examples:

Choose R, D/F, N_r and N_s

Choose R, $\overline{V}/B$, N_r and N_s

Equivalent because D/F and $\overline{V}/B$ are directly related:

$$\overline{V}/B = \frac{(D/F)(R+1)-(1-q)}{1-(D/F)} \qquad D/F = \frac{\overline{V}/B + (1-q)}{R+1+\overline{V}/B}$$

Reboil ratio can be called S

Guess x_D; calculate x_B; construct Mc-Cabe-Thiele diagram; step from top to bottom of column; check whether last step ends at x_B; repeat

Let's do this!

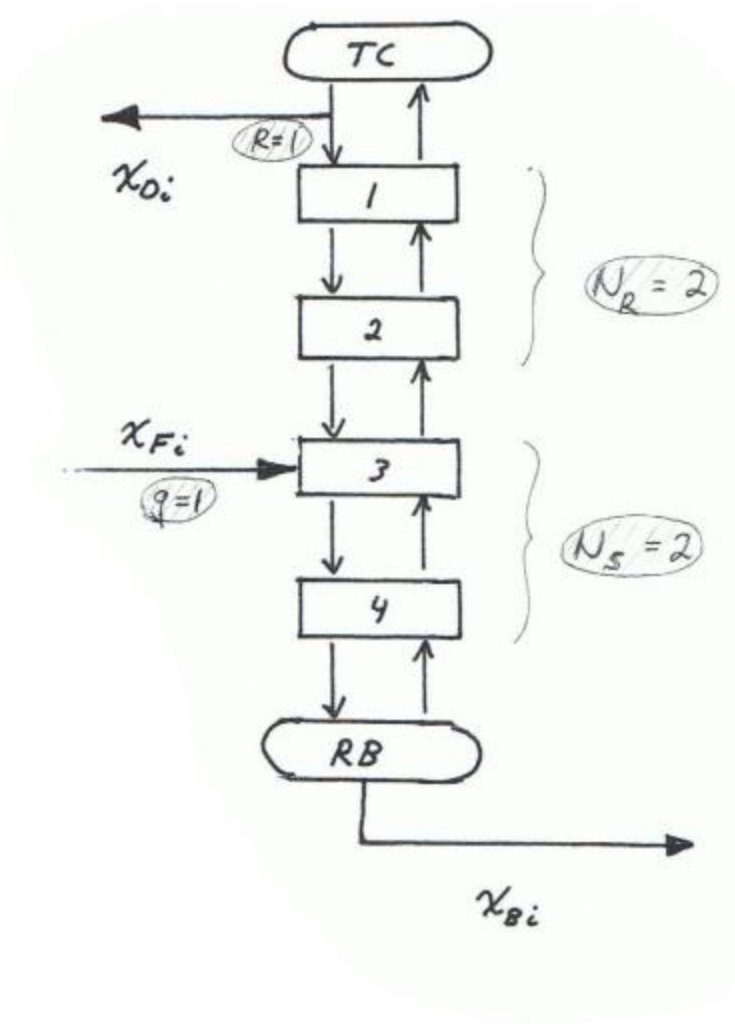
Let's do a performance calculation!

Total Condenser

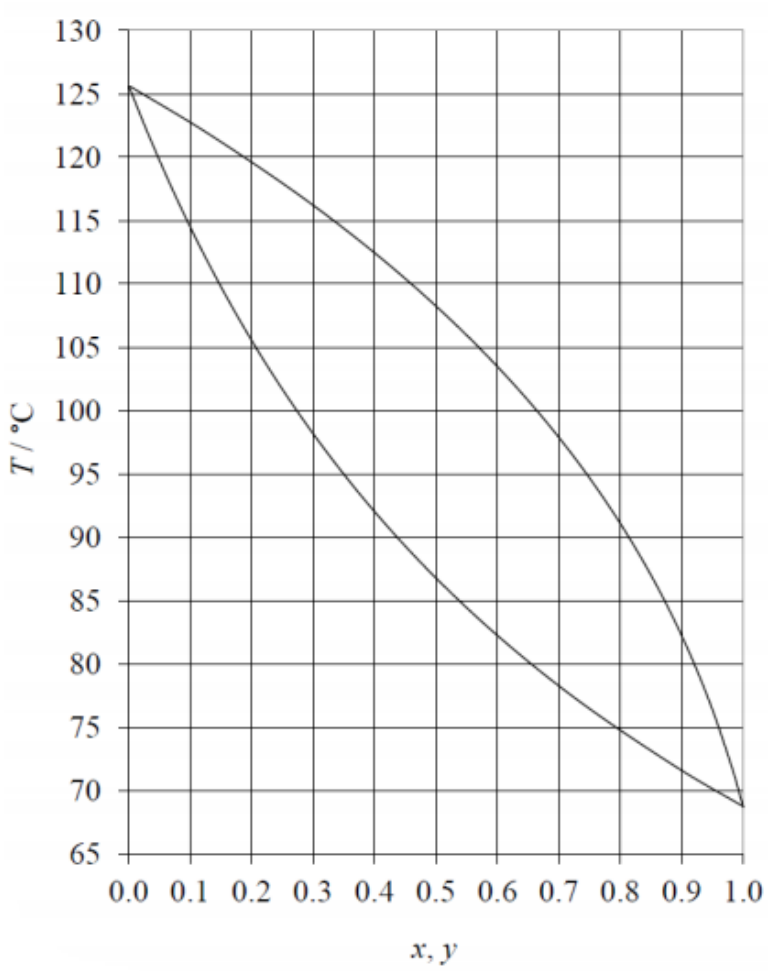
$N_r = 2$ ideal stages in the rectifying section and $N_s = 2$ ideal stages in the stripping section (i.e., 4 ideal stages with feed entering on ideal stage 3 counting down from the top), and a high-quality reboiler. Suppose feed enters as saturated liquid with composition as given in the following table. The column is operated with reflux ratio $R = 1.0$ and distillate to feed ratio $D/F = 0.50$. What are the temperatures and compositions of the distillate and bottom product streams emerging from the column?

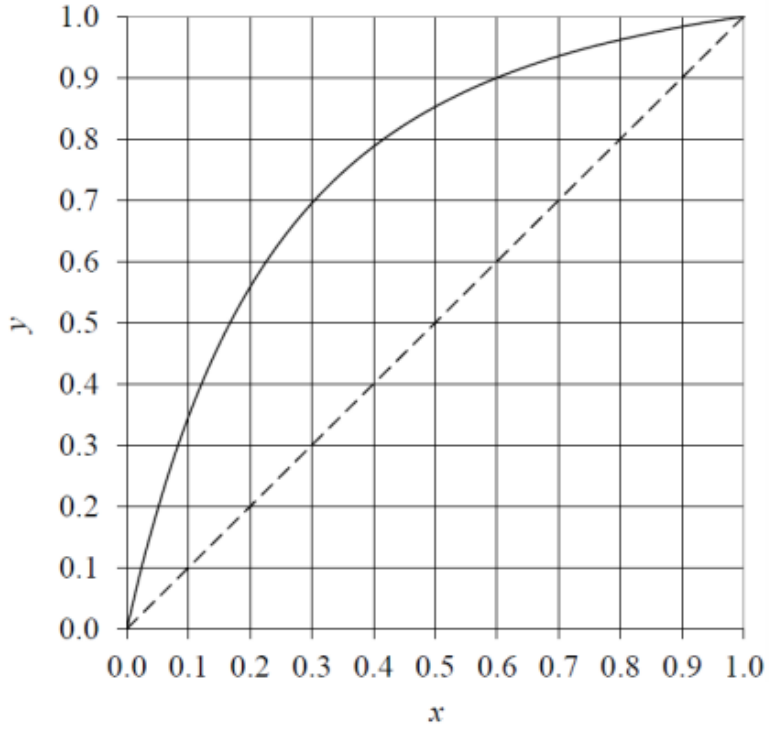
Component	x_{Fi}
n-butane	0.00
n-pentane	0.00
n-hexane	0.50
n-heptane	0.00
n-octane	0.50
n-nonane	0.00
n-decane	0.00

← Good thing this is a binary mixture!

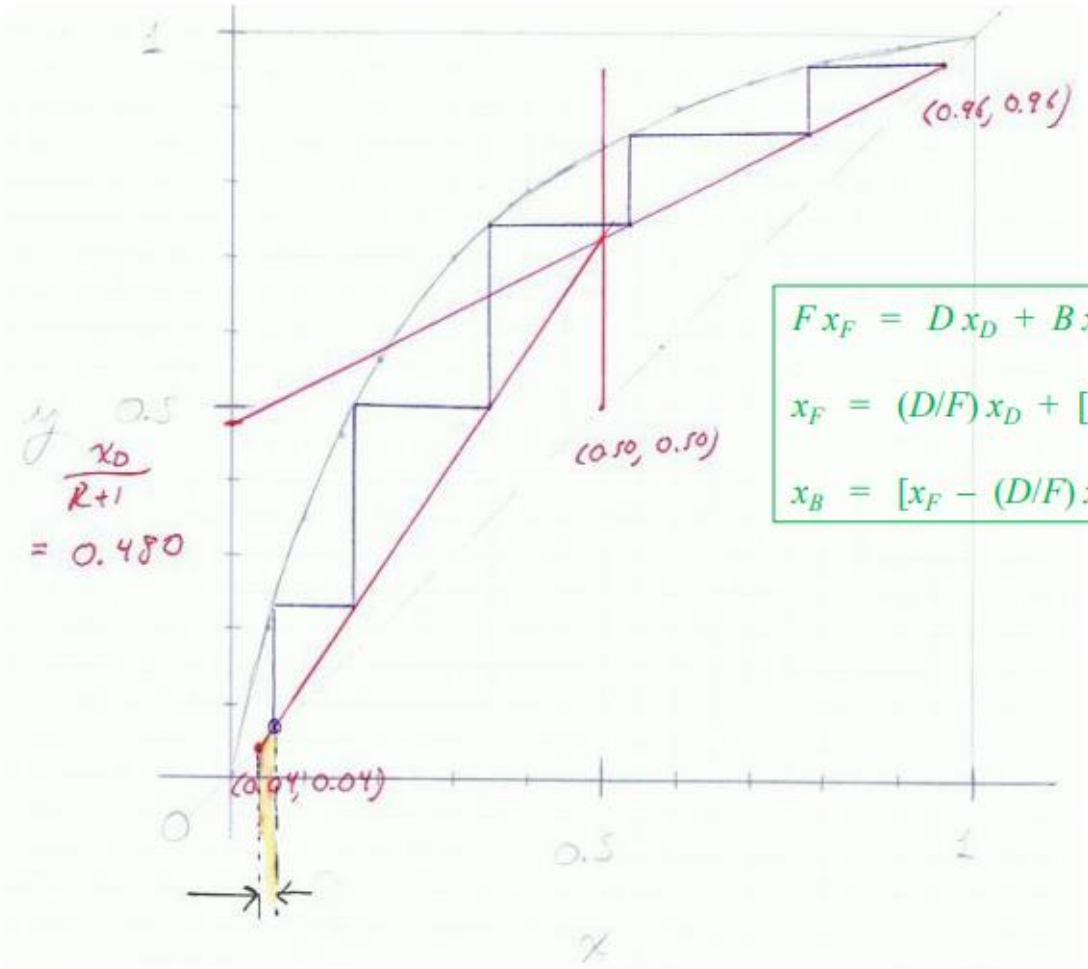

TC
R=1
x_{Di}
1
2
$N_R = 2$
x_{Fi}
q=1
3
4
$N_S = 2$
RB
x_{Bi}

Data for *n*-hexane + *n*-octane at 1 atm





Guess x_D = 0.96 → x_B = 0.04 by overall mass balance



$$F x_F = D x_D + B x_B$$

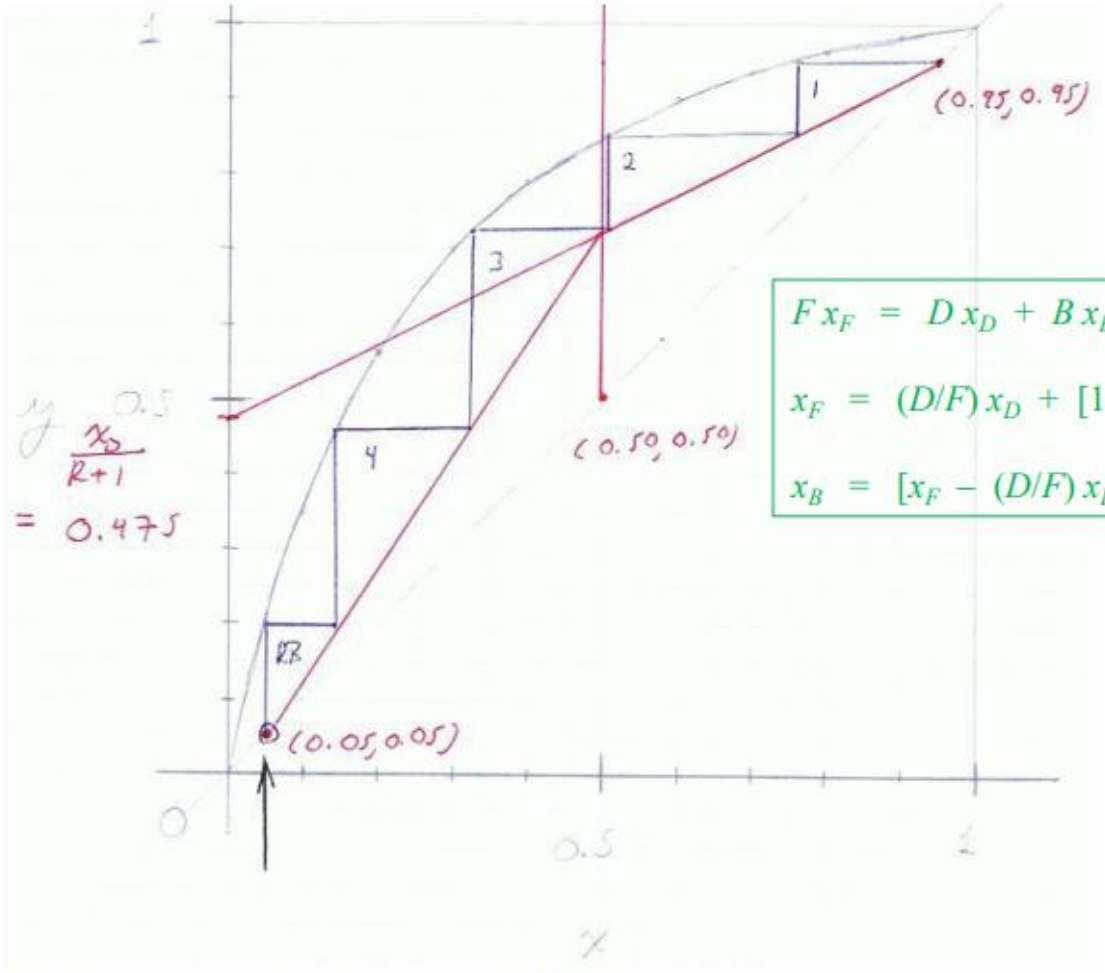
$$x_F = (D/F) x_D + [1 - (D/F)] x_B$$

$$x_B = [x_F - (D/F) x_D] / [1 - (D/F)]$$

→ x_B = 0.06 by stepping (tray-to-tray calculations)

Don't match → guess again

Guess x_D = 0.95 → x_B = 0.05 by overall mass balance



$$F\,x_F = D\,x_D + B\,x_B$$

$$x_F = (D/F)\,x_D + [1-(D/F)]\,x_B$$

$$x_B = [x_F - (D/F)\,x_D] \,/\, [1-(D/F)]$$

→ x_B = 0.05 by stepping (tray-to-tray calculations)

Perfect match → guess was correct!

Remarks

Both design and performance calculations involve either graphical or algebraic/ computational tray-to-tray calculations

Performance model involves an outer loop for adjusting the distillate composition ($x_{D,i}$ for $i = 1, \ldots, I-1$) until a certain set of conditions is satisfied, namely

$x_{B,i}$ by mass balance $=$ $x_{B,i}$ by tray-to-tray calculations for $i = 1, \ldots, I-1$

Design and optimization of a distillation column involves a further outer loop whereby parameters/specs. of a performance model are adjusted until an optimum design is reached