Chapter 7: Part B

Graphical "stage to stage" calculation, i.e. the "McCabe-Thiele" Method

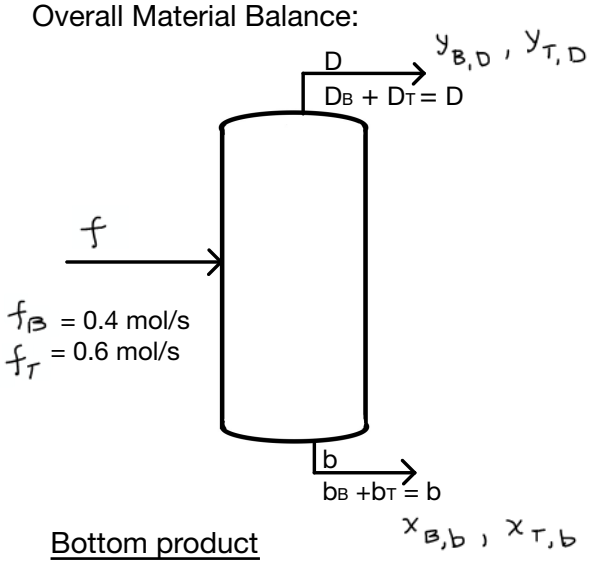
Example: Benzene-Toluene distillation

B= benzene
T= toluene

Specify the following:
1. Feed Pressure (P_f)
2. Column pressure = 1 atm $\Rightarrow \alpha_{BT} = 2.25$
3. Feed flow rate = 1 mol/s
4. $z_B = 0.4$
5. and 6. Feed is saturated liquid (this is equivalent to specifying T_f and Q_f)
7. Reflux = 1 mol/mol of feed
8. 90% benzene is recovered in top product
9. Purity of benzene in top product is $x_{B,d} = 0.95$

Design Problem: Feed plate location will be varied until *n* + *m* (total number of plates) is minimized

Overall Material Balance:



90% of B recovered into top product:
$(0.9) \cdot (0.4) = 0.36$ mol/s $= D_B$

95% purity of B in top product:

$$\frac{0.36}{0.36 + D_T} = 0.95 \Rightarrow D_T = 0.019$$

Total flow of the product

$D_B + D_T = 0.36 + 0.019 = 0.379$ mol/s

also $y_{B,D} = 0.95$
$y_{T,D} = 0.05$

Bottom product

molar flow of B:

$0.4 - 0.36 = 0.04$ mol/s $= b_B$

(f_B, D_B)

molar flow of T:

$0.6 - 0.019 = 0.581$ mol/s $= b_T$

(f_T, D_T)

Total flow in bottom product: $b = b_B + b_T = 0.62$ mol/s

Composition

$$x_{B,b} = \frac{b_B}{b} = \frac{0.04}{0.62} = 0.064 \qquad x_{T,b} = 1 - 0.064 = 0.936$$

Internal Flows (assume constant molar overflow)

All quantities are in mol/s

$V = L + D = 1.379$ mol/s

0.379

1

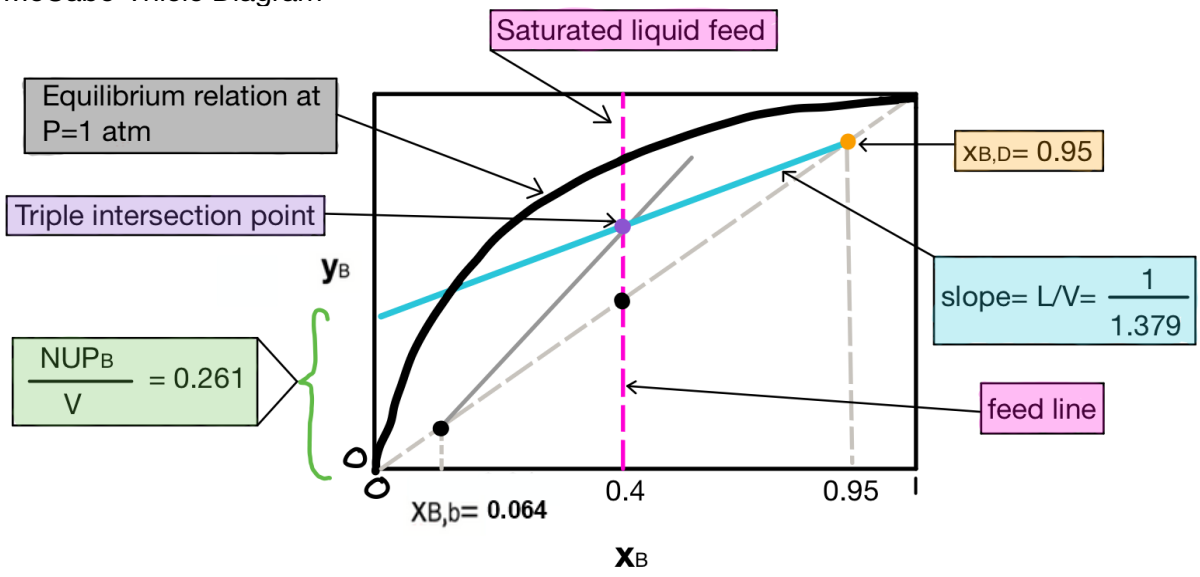
given in prob statement

$L' = L + F$

1 1

$V' = L' - b = 2 - 0.621 = 1.379$ mol/s

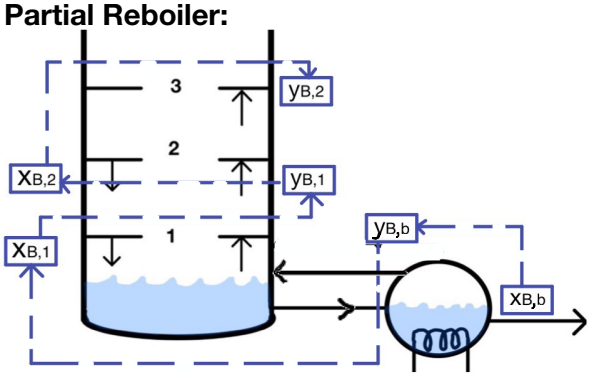
McCabe-Thiele Diagram

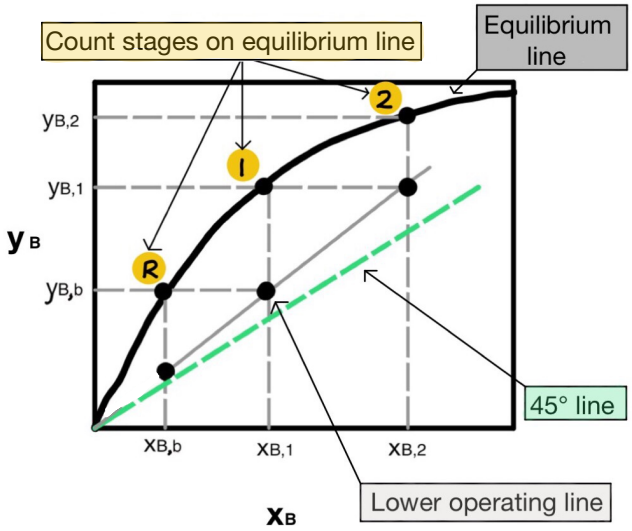


Intercept:

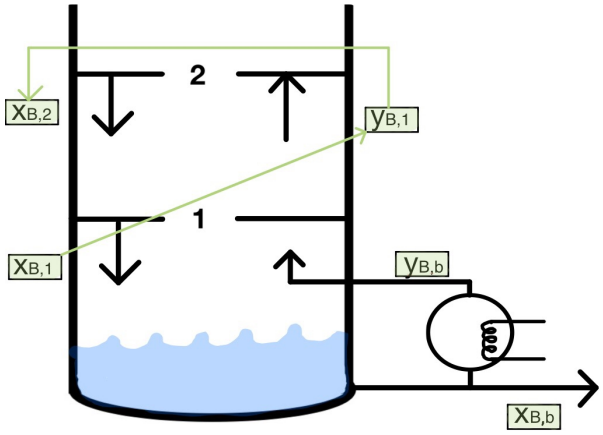
$y = \frac{L}{V}x + \frac{y_{B,D}D}{V} \rightarrow \frac{NUP_B}{V}$

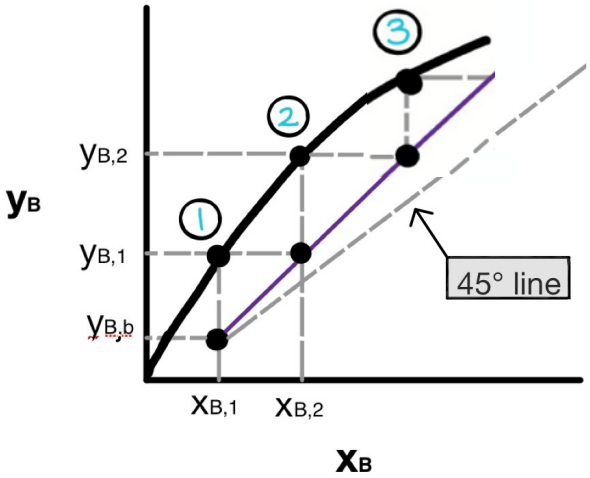
Partial Reboiler:



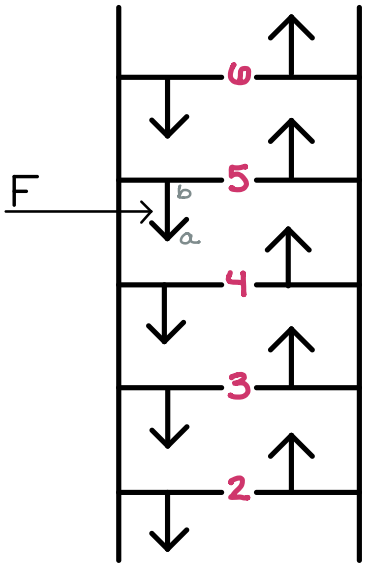


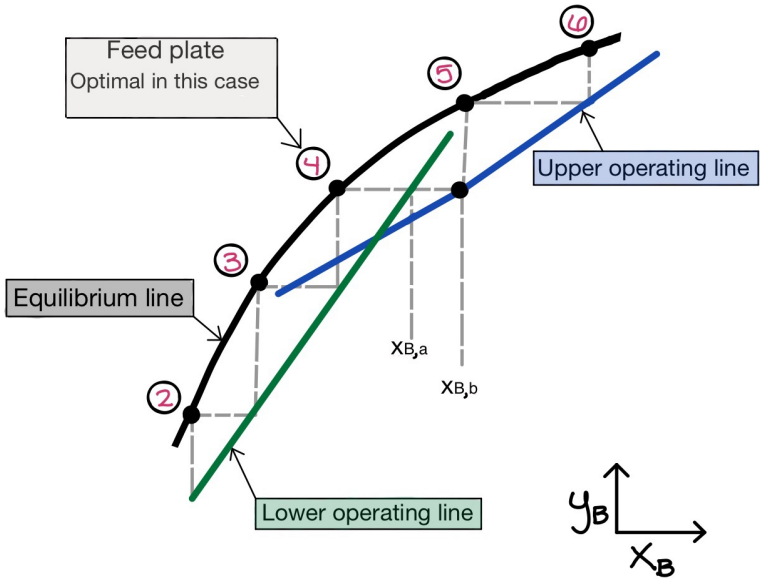
Total Reboiler:



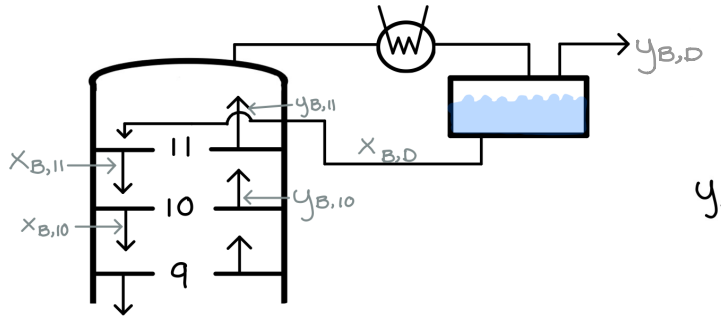


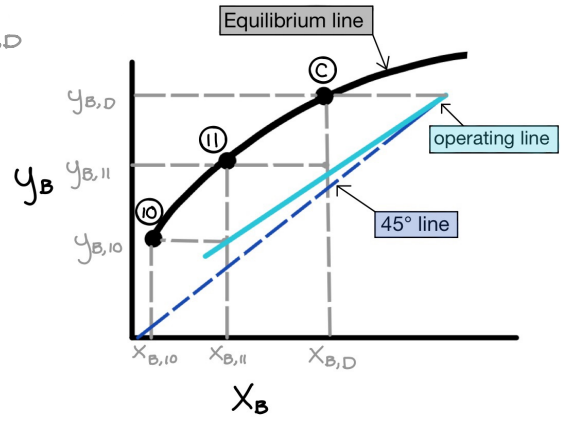
Feed Stage:



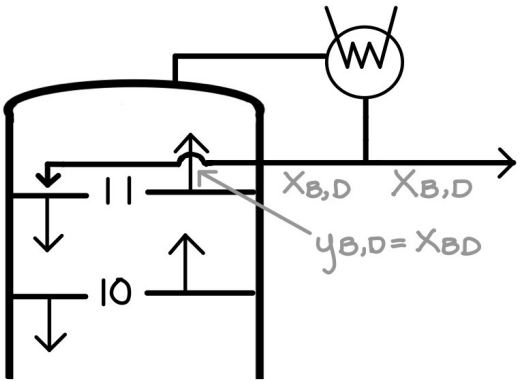


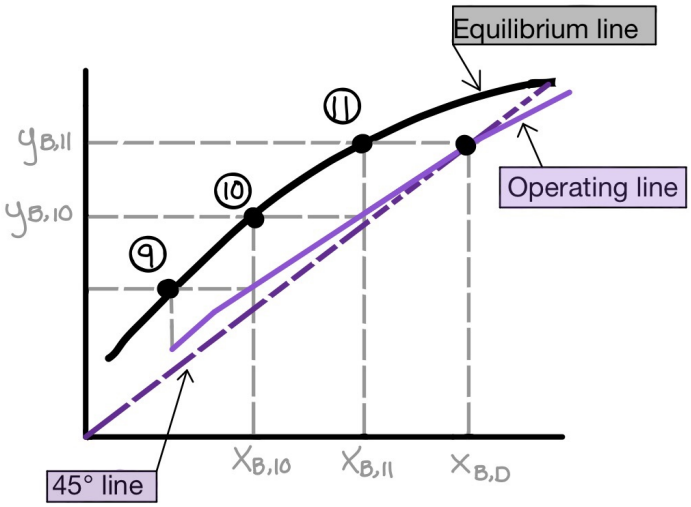
Condenser (partial):





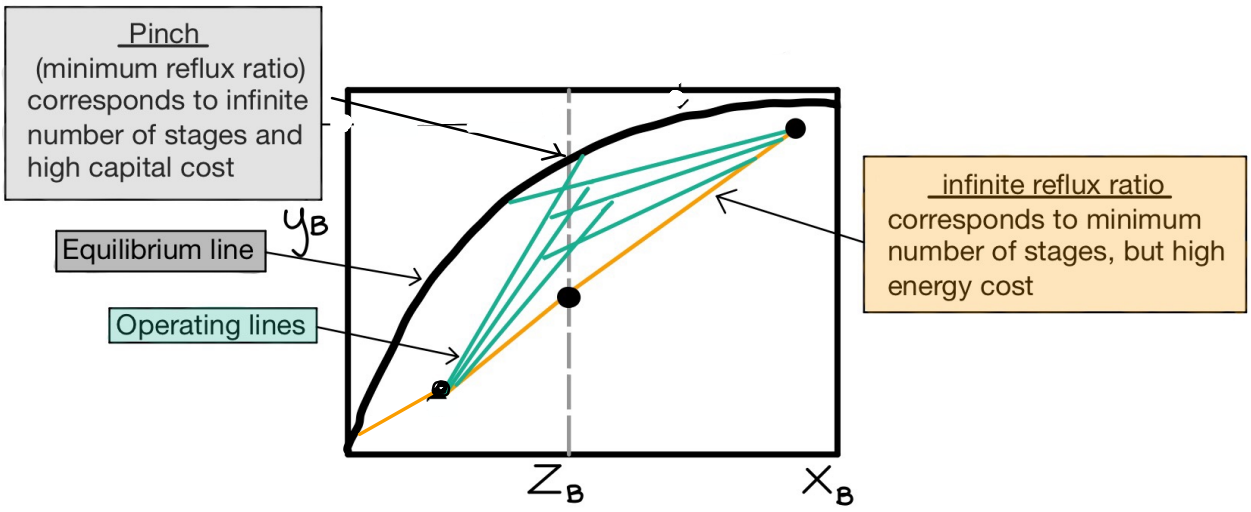
Total Condenser:

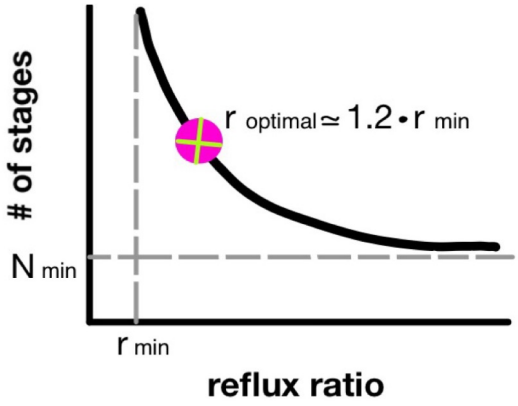


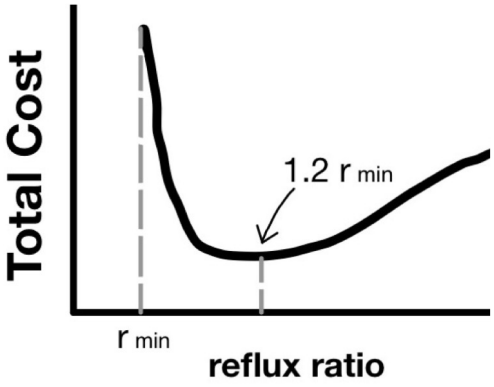


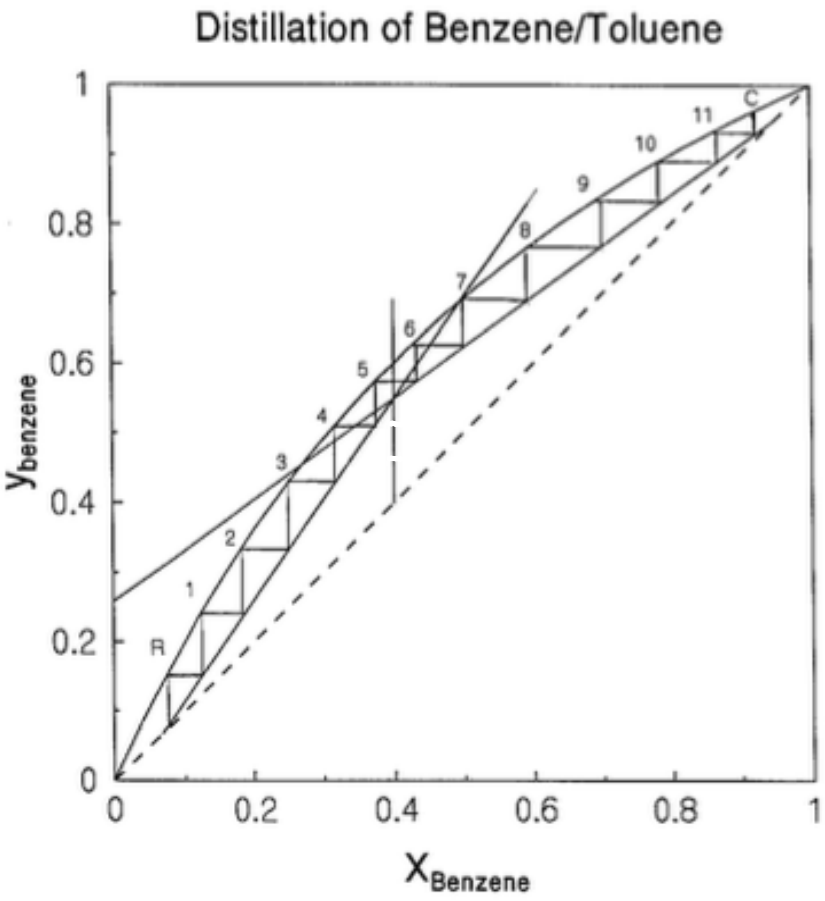
Reflux Ratio: $r = \frac{L}{D}$

Slope of upper operating line = $\frac{L}{V} = \frac{r}{r+1}$








Distillation of Benzene/Toluene
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
$y_{benzene}$
$x_{Benzene}$
R
C
1
2
3
4
5
6
7
8
9
10
11