In-Class Exercises n° 03
(Distillation – Binary distillation: Mc-Cabe–Thiele method)

Exercise 01:

A continuous binary distillation separates component A (more volatile) from component B (less volatile). Feed and product data:

- Feed flow: $\mathbf{F = 100\ kmol/h}$ (molar basis; value used only for flow-rates if needed)
- Feed composition (mole fraction A): $\boldsymbol{x_F = 0.50}$
- Desired distillate composition: $\boldsymbol{x_F = 0.95}$
- Desired bottoms composition: $\boldsymbol{x_F = 0.05}$
- Relative volatility (assumed constant): $\boldsymbol{\alpha = 2.0}$
- Feed condition: saturated liquid (so $\boldsymbol{q = 1}$)
- Assume ideal stages and constant molar flows (no significant heats of mixing, constant molar overflow applies)

Using the McCabe–Thiele graphical method:

- Construct the equilibrium curve $y = \frac{\alpha x}{1+(\alpha-1)x}$ and the 45° line.
- Draw the q-line.
- Determine the minimum reflux ratio R_{min}.
- Pick a practical reflux ratio $R = 1.5R_{min}$. For the R: draw the rectifying and stripping operating lines, locate the feed stage intersection, and use the step-off construction to determine the number of theoretical stages (including the reboiler as one stage if you treat the reboiler as a stage).
- Report the number of theoretical stages and the feed stage location (counting stages from the top).

Exercise 02:

A saturated liquid mixture containing **60 mole %** benzene and **40 mole %** toluene is to be distilled continuously into a distillate product containing **90 mole %** benzene and the bottom product containing **5 mole %** benzene. The fractional distillation column will operate at approximately constant pressure of 1 atm. The **reflux ratio** is **2**. How many theoretical plates must the column have if the feed is introduced into the eighth plate?

Data: $\mathbf{z_F = 0.6}$; $\mathbf{x_D = 0.9}$; $\mathbf{x_W = 0.05}$; $\mathbf{R = 2}$.
Feed is saturated liquid

Equilibrium data are:

x	0	0.017	0.075	0.13	0.211	0.288	0.37	0.411	0.581	0.78	1
y	0	0.039	0.161	0.261	0.393	0.496	0.591	0.632	0.777	0.9	1

Exercise 03:

A liquid mixture of methanol-water is to be distilled in a plate tower. The feed of **200 kmol/h** is liquid and contains **48% mol** of methanol. It is desired to obtain a distilled product that contains **90% mol** of methanol and a bottom product that only contains **5% mol** of methanol. It is fed at the same amount of liquid and vapor.

a) Calculate the minimum reflux.
b) Calculate the number of stages required if **1.5 times** the minimum reflux is used.
c) Identify at which stage (dish) you should be fed.

x	0.079	0.17	0.28	0.40	0.56	0.75	1
y	0.23	0.43	0.59	0.72	0.83	0.92	1

Exercise 04:

550 kmol/h of a binary mixture water/acetic acid (70 mol% water) is separated by distillation in a bottom fraction with 98 mol% acetic acid and a distillate containing 5 mol% acetic acid. The relative volatily of water over acetic acid is 1.85

a) Calculate the amount of distillate and bottom product this distillation yields?
b) Determine graphically the minimum number of stages.

The external reflux ratio R (= L'/D) is set at 3. The boilup ratio in the stripping section (= V"/B), is set to 10.

c) Determine graphically the required number of equilibrium stages under these conditions.
d) Determine graphically the optimal location for the feed stage.
e) Determine graphically the slope of the feed line and from that the vapor fraction in the feed.